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GCA Corp, Bedford, Mass GCA Technology Div

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IMPROVEMENTS TO SINGLE-SOURCE MODEL VOLUME 2: TESTING AND EVALUATION OF MODEL IMPROVEMENTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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16. ABSTRACT

The main purpose of this study was to determine whether alternate methods for stability index assignment and dispersion calculation would yield better agreement between measured and calculated cumulation frequency distributions of 1-hour SO_2 concentrations when used in the EPA Single Source Model. The following dispersion curves were tested: Pasquill-Turner, Gifford-Briggs, Smith-Singer and F. B. Smith. A fractional stability assignment technique based upon the work of F. B. Smith was also investigated. Based upon model validation results for the Canal Power Plant in Massachusetts and the Muskingum Power Plant in Ohio, the Pasquill-Turner dispersion curves and stability index assignment algorithm currently used in the model were found to give the best agreement with measured concentration distributions. During the course of the study the incorporation of a variable stack gas exit velocity was evaluated and found not to appreciably affect the model predictions.

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SECTION I

INTRODUCTION

The purpose of this study is to test a number of suggested improvements to the EPA Single Source Model (CRSTER). In particular three alternate methods for the parameterization of vertical and horizontal dispersion coefficients with distance will be evaluated along with two additional stability class selection algorithms. The predictions of each modified version of the Single Source Model will be compared with actual concentration measurements so that these potential model improvements can be evaluated. Another objective of this study was to determine whether the use of a variable buoyancy flux in the plume rise equation in the model would yield better predictions.

During two previous EPA sponsored projects[1,2] GCA carried out validation studies for the Single Source 24-Hour Model at four separate power plant sites. Model predictions of 1-hour and 24-hour SO_2 concentration frequency distributions were carried out based upon emission parameters and hourly meteorological data and compared with the corresponding frequency distributions of SO_2 concentration measurements corrected for background contributions.

In the first validation exercise, which was performed for the Canal Power Plant in southeastern Massachusetts, concentration predictions were made for a variety of emissions and meteorological data bases ranging in degree of resolution from monthly average emission rates taken from FPC Form-67 and hourly meteorological data from the nearest weather station to actual hourly emissions and on-site wind speed and direction

data in conjunction with hourly stabilities and mixing heights extracted from the weather station observations. Regardless of the choice of input data sets the model was found to underpredict both 1-hour and 24-hour SO_2 concentrations. With the exception of one receptor location, the ratios of measured minus background to predict second highest yearly SO_2 concentrations fell between 1.0 and 2.0. The corresponding ratios for the 24-hour concentrations, again neglecting one receptor location, ranged from 1.2 to 5.4 with an arithmetic mean of 3.2.

To determine whether the underprediction found for the Canal Plant was due to the coastal location of the plant site or some weakness in the model itself, three power plant sites were chosen in Ohio for additional tests of the model. Source characteristics and emission rates for the J. M. Stuart, Muskingum and Philo power plants were used in conjunction with surface and upper air meteorological data from nearby weather stations to generate model estimates of SO_2 concentrations for the 1-hour and 24-hour averaging times employed in the Canal plant study. With the exception of the Philo plant the predicted 1-hour SO_2 concentrations were in much better agreement with measurements than for the Canal plant study. The average ratio of second highest measured to predicted 1-hour SO_2 concentrations was 1.02 and 1.10 for the Stuart and Muskingum plants respectively. One-hour SO_2 concentrations for the Philo plant were overpredicted by a factor of 2, a circumstance due in large part to the inadequacy of the Single Source Model to handle the dispersion effects associated with complex terrain, particularly for those receptor locations with elevations comparable to that of the stack top. The predicted second highest 24-hour SO_2 concentrations for the J. M. Stuart and Muskingum plants were in better agreement with the measured values than in the case of the Canal plant with the measured to predicted ratios of 1.5 and 2.0 for the J. M. Stuart and Muskingum plants respectively.

Based upon these model validation studies two problems areas could be identified. The first concerned the underprediction of second highest 24-hour concentrations at three of the four plants studied. To a large degree

this tendency to underpredict 24-hour concentrations may be traced to the method by which 24-hour predictions are obtained from 1-hour concentration calculations. For the calculation of 1-hour concentrations the Single Source Model requires that the wind flow vector remain constant for the entire hour so that no mechanism exists for a smooth transition from one hourly flow direction to the next. While this assumption does not seriously effect the quality of the peak 1-hour concentration predictions, the resulting deficiency in low and intermediate concentrations (i.e. large number of zero concentration predictions) may lead to an underestimate in the associated 24-hour concentrations. An alternate method for the estimation of peak 24-hour concentrations is through the application of peak to mean ratio distribution statistics. In each of the model validation studies distributions of peak 1-hour to average 24-hour SO_2 concentration ratios were constructed from actual hourly SO_2 concentration measurements corrected for background. For the four plants studied the geometric means of these distributions ranged from 7.3 to 7.9 and the standard geometric deviations from 1.5 to 1.7. If the second highest predicted 1-hour SO_2 concentration were found to be accurate, then an estimated second highest 24-hour SO_2 concentration obtained by dividing the 1-hour value by the geometric mean of the 1-hour to 24-hour peak to mean ratio should be accurate to at least a factor of 2. Volume I of this study was devoted to a further examination of these ratio distributions to determine their sensitivity to the use of successively higher threshold values of peak 1-hour SO_2 concentrations.

The second area of concern dealt with the theoretical bases for the model predictions, namely, the plume rise formulation, stability class selection procedure and the choice of parameters for the calculation of vertical and horizontal plume dispersion coefficients. The basic question was whether the use of alternate techniques would improve the agreement between predicted and measured 1-hour SO_2 concentrations, particularly at the Canal plant. The Briggs[3,4,5] plume rise estimates currently incorporated in the Single Source Model represent the best fit to currently existing data. For the Canal plant study, a modification was made to the plume rise

computation in the model to include the effect of stack downwash but this modification did not improve the quality of the predictions to a significant degree. On the other hand, there are a number of techniques different from the Pasquill-Turner method which is currently in use for the classification of stabilities and the calculation of dispersion coefficients. In Section II we shall describe some of these techniques and describe the manner in which they were included in the Single Source Model. Section III will deal with the source and meteorological input data bases to be used in the test of potential model improvements. In Section IV we shall present the model validation results for the alternate dispersion calculation techniques and draw a conclusion as to the adequacy of the existing model formulation. Also, in Section IV we shall investigate the utility of incorporating a variable volume flux in the Single Source Model.

SECTION II

SURVEY OF DISPERSION CALCULATION METHODS

DESCRIPTION OF THE EXISTING MODEL

We shall begin our discussion of dispersion calculation methods with a description of the EPA Single Source Model as it currently exists. The program, which was developed by the EPA Meteorology and Assessment Division, calculates hourly and daily concentrations for an array of receptor locations and maximum hourly and daily pollutant concentrations for a year along with the meteorological conditions which can lead to these maxima. These concentrations are written on magnetic tape for the 252 receptor positions situated at each of 36 directions from the source and seven different distance ranges. The normal version of the model has five distances and 180 receptors. The seven distances and 252 receptors occur only in the special OCA adaptation. The model can handle from 1 to 19 sources but treats all of them as if they were at the same physical location. The expression used for evaluation of 1-hour pollutant concentrations downwind of a point source is the Gaussian plume equation[6,7] given by

$$\chi(x,y,z) = \frac{Q \exp\left(\frac{-y^2}{2\sigma_y^2(x)}\right)}{2\pi\,\sigma_y(x)\,\sigma_z(x)\,u}\left[\exp\left(-\frac{(z-h(x))^2}{2\sigma_z^2(x)}\right) + \exp\left(-\frac{(z+h(x))^2}{2\sigma_z^2(x)}\right)\right] \quad (1)$$

where x = distance along plume axis (m)

y = horizontal distance from plume axis (m)

z = distance above surface (m)

$\chi(x,y,z)$ = concentration of pollutant (g/m^3)

Q = effective emission rate of pollutant distance x (g/sec)

$\sigma_y(x)$, $\sigma_z(x)$ = horizontal and vertical dispersion coefficients for a particular atmospheric stability (A,B,C,D,E,F) and distance x

u = wind speed at source height (m/sec)

h(x) = effective emission height at distance x (m)

The variation of σ_y and σ_z with distance was first parameterized by Gifford[6] as shown in Figures 1 and 2. These curves represent a fit to a number of concentration field measurements including those made during the Prairie Grass study[8] conducted during the summer of 1956. Although these plume dispersion estimates were based largely upon ground level releases they are also generally applied to elevated point sources. Criteria for selection of a particular stability class were first suggested by Pasquill[9] and Meade[10] and are listed in Table 1. The measurements upon which these curves were based were taken within 1 km of the source, the shape of the σ_z curves beyond this distance is somewhat uncertain especially for the A and B stability classes. For the σ_z curves used for the Single Source Model the variation of dispersion with distance for the A and B stabilities is represented by a simple power law beyond 500 m and 700 m, respectively, as shown in Figure 3.[7] A more detailed stability class assignment algorithm than the one given in Table 1 was suggested by Turner[11] and is currently incorporated in the meteorological preprocessor program used in conjunction with the Single Source Model. The details of this method are presented in Appendix A. The Single Source Model makes use of an additional stability class, G, for which the assumption is made that the plume never reaches the ground.

Surface meteorological input to the model consists of hourly surface observations of wind speed (knots), wind direction sector (1-36), temperature (°F), and total cloud cover (tenths). The format for these data is that used by the National Climatic Center for WBAN-144 hourly surface observations. These data along with twice daily mixing heights are input into a preprocessor program which in turn writes a tape containing hourly values of stability index, mixing height, temperature, windspeed, flow

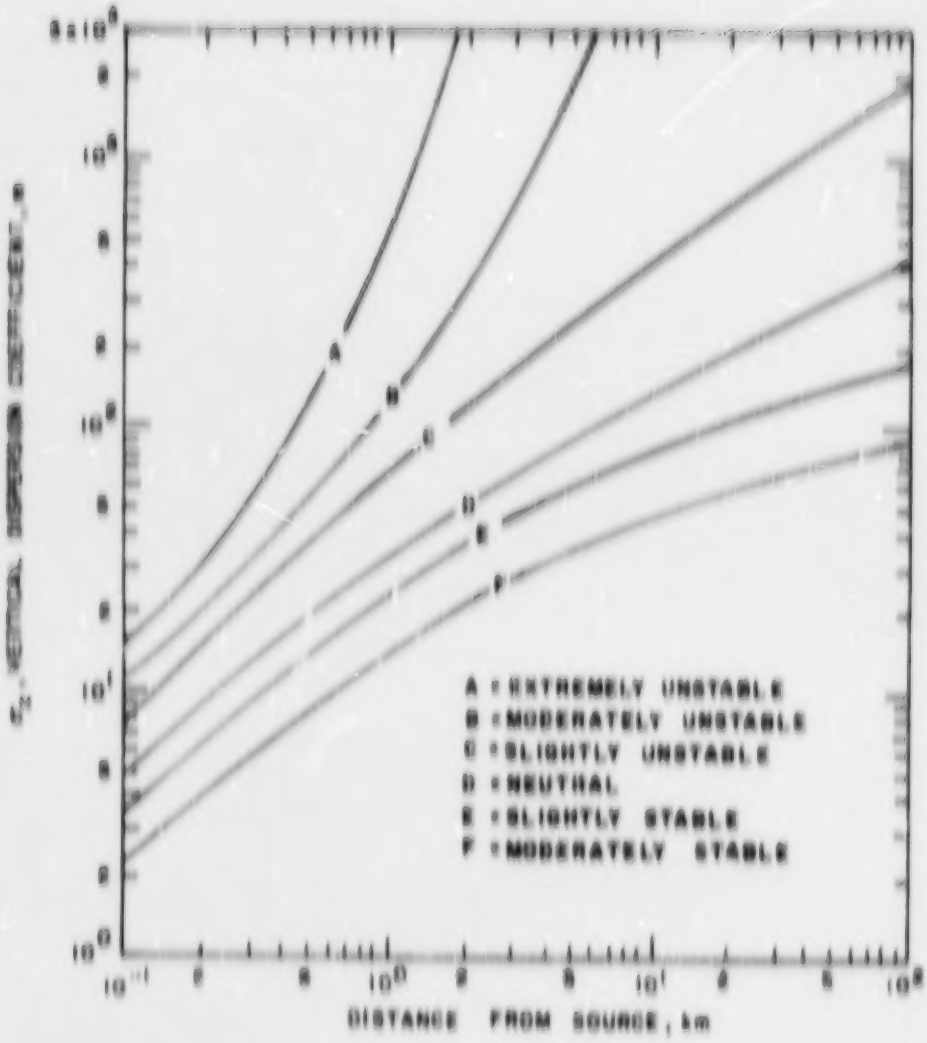

Figure 1. Vertical dispersion coefficient as a function of distance according to Gifford[5]

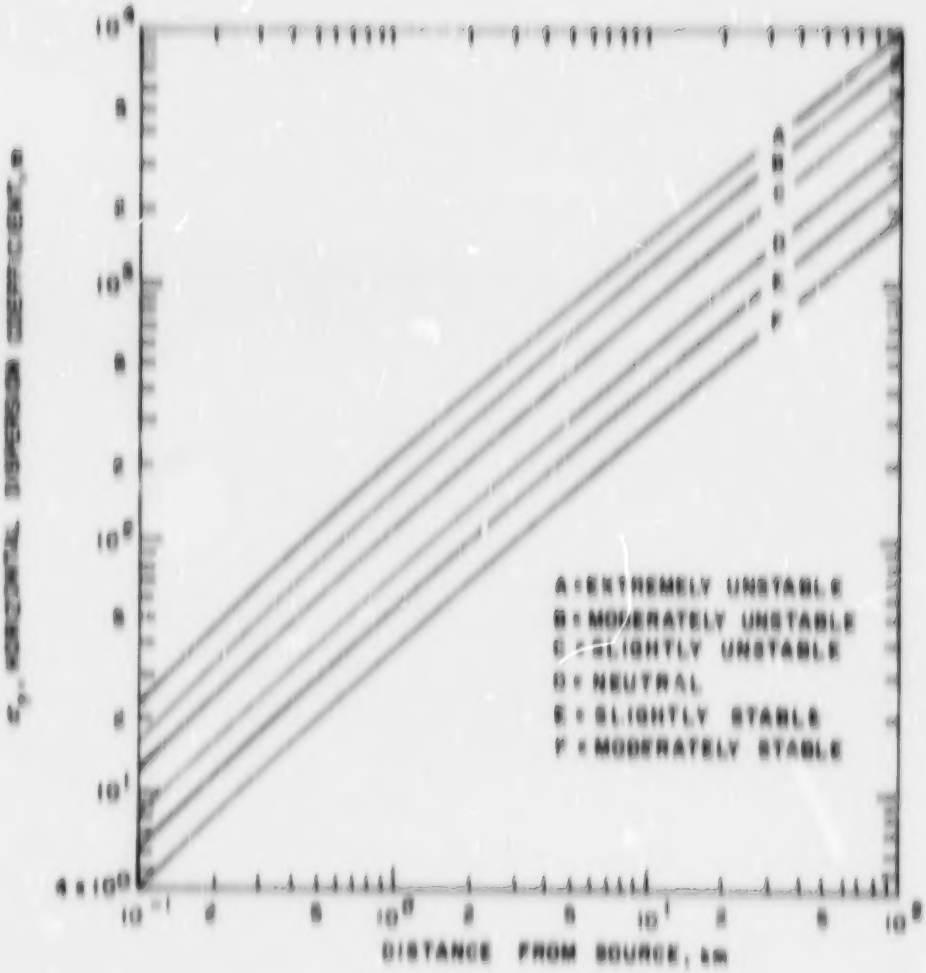

Figure 2. Horizontal dispersion coefficient as a function of distance according to Gifford[8]

Table 1. METEOROLOGICAL CATEGORIES ACCORDING TO PASQUILL[9] AND HEADE[10]

Surface wind speed, m/sec	Daytime insolation			Thin overcast or ≥ 4/8 cloudiness	≤ 3/8 cloudiness
	Strong	Moderate	Slight		
< 2	A	A-B	B		
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
> 6	C	D	D	D	D

A - Extremely unstable conditions

B - Moderately unstable conditions

C - Slightly unstable conditions

D - Neutral conditions (Applicable to heavy overcast, day or night)

E - Slightly stable conditions

F - Moderately stable conditions

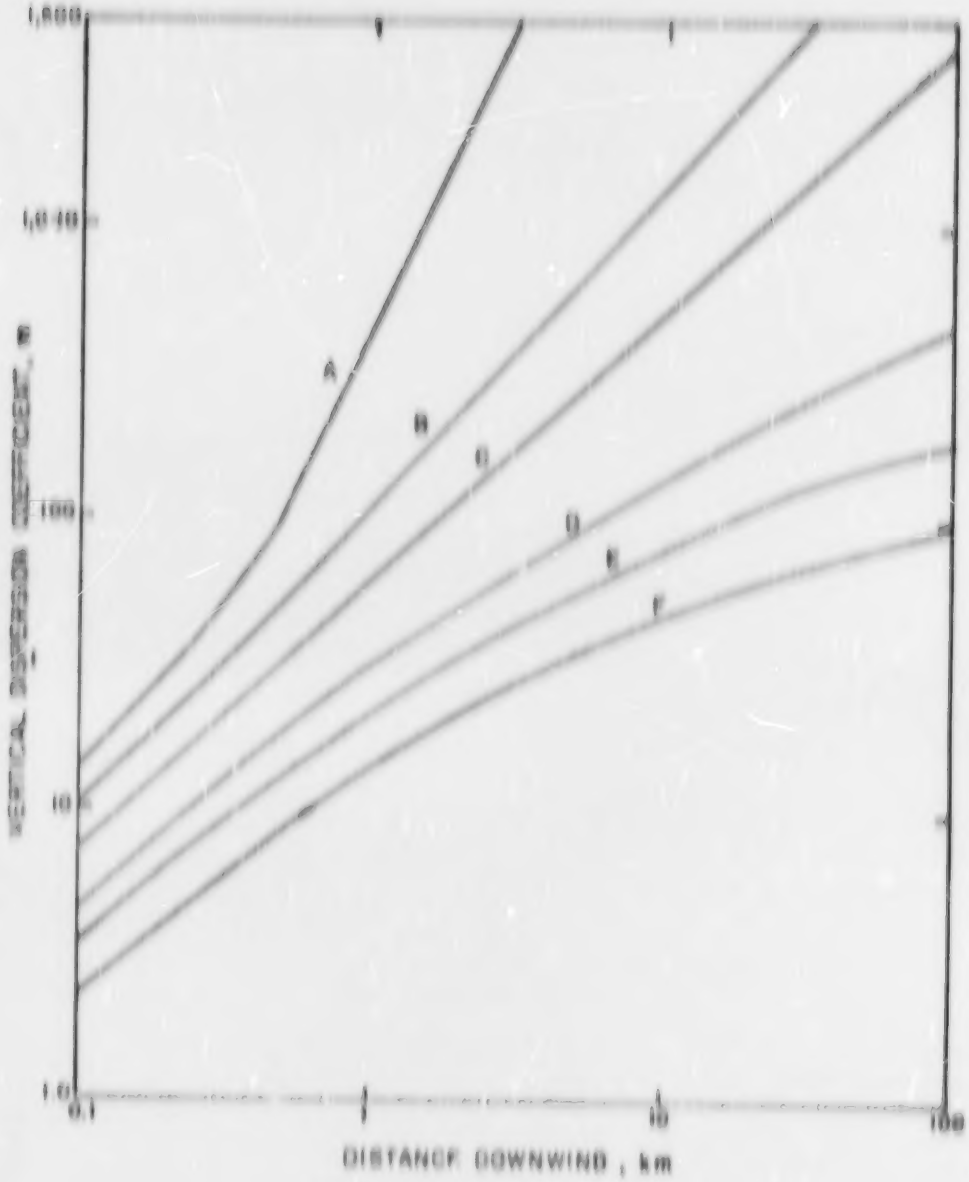

Figure 1. Vertical dispersion coefficient as a function of downwind distance from the source as currently employed in the Single Source Model[7]

vector (wind direction plus 180°), and randomized flow vector. The randomized flow vector is equal to the flow vector minus 4 degrees plus a random number between 0 and 9 degrees. The preprocessor output tape is then read by the Single Source Model which performs the actual concentration calculations. The twice daily mixing height data can be obtained from the National Climatic, Asheville, North Carolina. Missing data were filled in through interpolation.

Two different sets of hourly mixing heights are calculated by the preprocessor. One is for rural surroundings; the other is for urban locations. The way in which hourly mixing heights are determined from maximum mixing heights (MXDP) for yesterday (i-1), today (i) and tomorrow (i + 1) and minimum mixing heights (MNDP) for today (i) and tomorrow (i + 1) is depicted in Figure 4. For urban mixing height between midnight and sunrise the following procedure is used: if the stability is neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ (1), if stability is stable use $MNDP_i$ (2). For hours between sunrise and 1400, if the hour before sunrise was neutral, interpolate between $MXDP_{i-1}$ and $MXDP_i$ (3). For sunrise to 1400, if the hour before sunrise was stable, interpolate between $MNDP_i$ and $MXDP_i$ (4). For 1400 to sunset, use $MXDP_i$ (5). For hours between sunset and midnight, if stability is neutral interpolate between $MXDP_i$ and $MXDP_{i+1}$ (6), if stability is stable interpolate between $MXDP_i$ and $MNDP_{i+1}$ (7).

For rural mixing height between midnight and sunrise, interpolate between $MXDP_{i-1}$ and $MXDP_i$ (8). For hours between sunrise and 1400, if the hour before sunrise was neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ (9). For sunrise to 1400, if the hour before sunrise was stable, interpolate between 0 and $MXDP_i$ (10). For 1400 to sunset, use $MXDP_i$ (11). For sunset to midnight, interpolate between $MXDP_i$ and $MXDP_{i-1}$ (12).

Wind speeds u_o measured at instrument height h_o (7 meters is common for weather stations) are adjusted by means of a stability dependent power

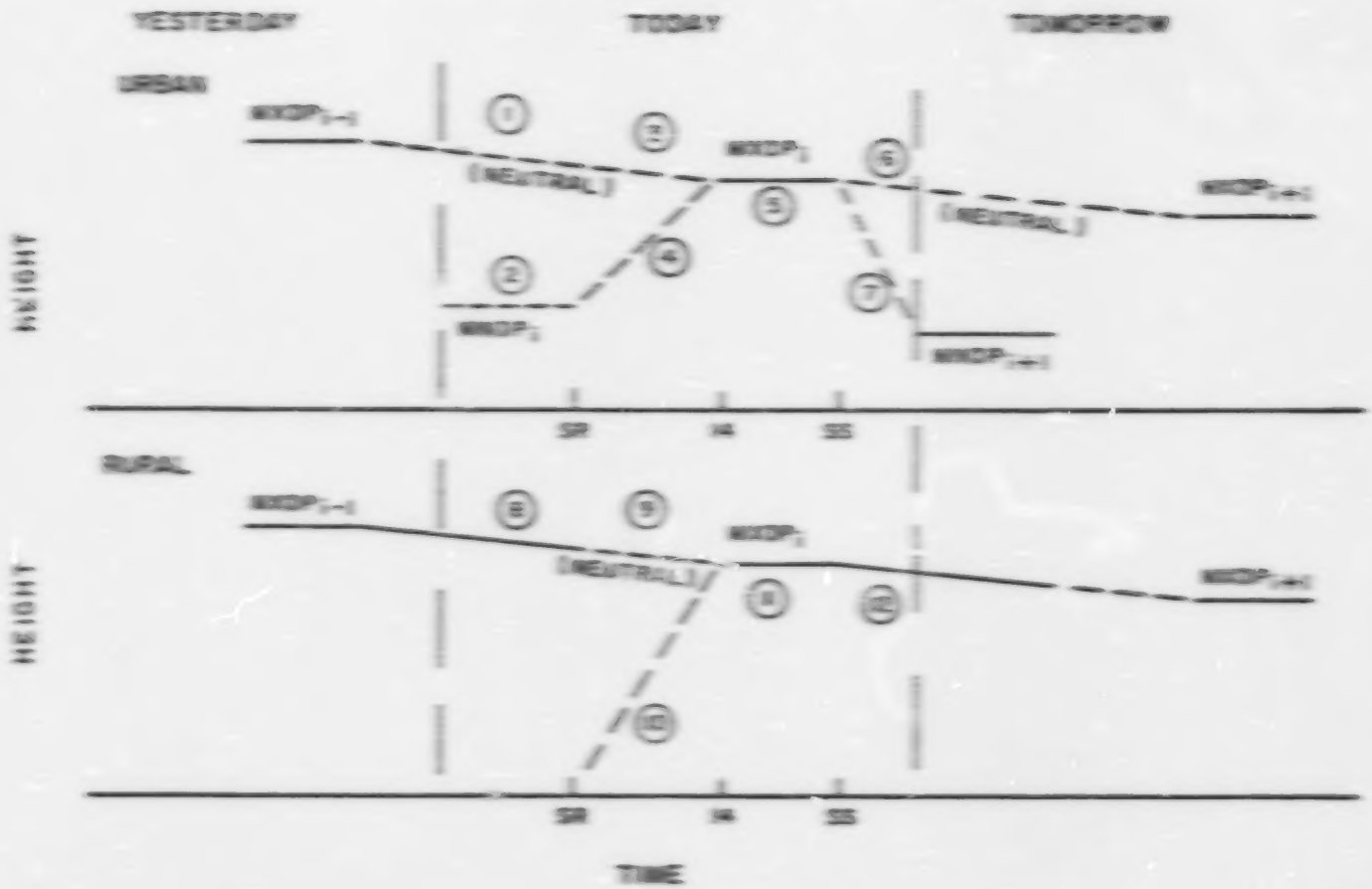

Figure 4. Determination of hourly mixing heights

law ($u = u_0 (h/h_0)^{\alpha}$) to correspond to values one would expect at the actual stack height h. The variation of the exponent α with stability is shown in Table 2. Plume rise is calculated on an hourly basis using the method of Briggs.[3-5] The effective stack height h(x) will be greater than the actual stack height h_s due to the buoyancy of the plume. The expression for h(x) for stabilities A through D is given by

$$h(x) = h_s + \Delta h \qquad (2)$$

where $\Delta h = 1.6F^{1/3}\, u^{-1}\, x^{2/3}$ for $x \leq 3.5x^*$

$\Delta h = 1.6F^{1/3}\, u^{-1}\, (3.5x^*)^{2/3}$ for $x > 3.5x^*$

$x^* = 14F^{5/8}$ when $F < 55\ m^4/sec^3$

$x^* = 34F^{2/5}$ when $F \geq 55\ m^4/sec^3$

$$F = gvr^2 \left(\frac{T_s - T_a}{T_s}\right)$$

g = gravitational acceleration (m/sec^2)

v = stack gas exit velocity (m/sec)

T_s = stack gas temperature (°K)

T_a = ambient temperature (°K)

Table 2. WIND PROFILE EXPONENTS (α) FOR DIFFERENT STABILITIES

Stability class	α
A	0.1
B	0.15
C	0.2
D	0.25
E	0.3
F	0.3

For stability classes E and F the plume rise becomes

$$\Delta h = 2.9\left(\frac{F}{us}\right)^{1/3} \qquad (3)$$

where $s = \frac{g}{\theta}\frac{d\theta}{dz}$

θ = potential temperature (^{o}K)

$\frac{d\theta}{dz}$ = 0.02 $^{o}K/m$ for stability E

$\frac{d\theta}{dz}$ = 0.075 $^{o}K/m$ for stability F

If the plume rise calculation indicates that the plume axis will rise above the mixing layer, then a zero concentration contribution is specified. If the final height plume is below the top of the mixing layer, the presence of the mixing boundary is accounted for in the Single Source Model by the incorporation of multiple image sources as was done to satisfy the zero flux condition at ground level. With this assumption Equation (1) is generalized to give

$$\chi(x,y,z) = \frac{Q \exp\left(\frac{-y^2}{2\,\sigma_y^2(x)}\right)}{2\pi\,\sigma_y(x)\,\sigma_z(x)} \left\{ \exp\left(-\frac{(z-h(x))^2}{2\,\sigma_z^2(x)}\right) \right.$$

$$+ \exp\left(-\frac{(z+h(x))^2}{2\,\sigma_z^2(x)}\right) + \sum_{n=1}^{N} \exp\left(-\frac{(z-h(x)-2jL)^2}{2\,\sigma_z^2(x)}\right)$$

$$+ \exp\left(-\frac{(z+h(x)-2jL)^2}{2\,\sigma_z^2(x)}\right) + \exp\left(-\frac{(z-h(x)+2jL)^2}{2\,\sigma_z^2(x)}\right)$$

$$\left. + \exp\left(-\frac{(z+h(x)+2jL)^2}{2\,\sigma_z^2(x)}\right)\right]\Bigg\} \qquad (4)$$

where L = depth of the mixing layer (m)
n = number of images considered

In practice only the first few image terms contribute significantly to the overall ambient concentration. For distances greater than $2\,x_L$, where x_L is given by $\sigma_z\,(x_L) = 1.6$, Equation (5) was approximated by

$$\chi(x,y,z) = \frac{Q \exp\left(\frac{-y^2}{2\,\sigma_y^2(x)}\right)}{\sqrt{2\pi}\,\sigma_y(x)\,U\,L} \qquad x > 2\,x_L \qquad (5)$$

Source input to the Single Source Model may possess several degrees of temporal resolution. In the seasonal version of the model an annual average SO_2 source strength is specified along with monthly variation factors. In addition to the seasonal factors, the diurnal version of the model employs hourly emission variation factors for each month of the year. A modification made to the model used in our validation studies allowed actual hourly source strengths to be utilized. A second modification made to the model allowed actual receptor elevations to be accounted for. In Section IV of this report we shall present the results of a validation of a version of the Single Source Model which allows the stack exit velocity to vary with the fuel consumption rate.

DESCRIPTIONS OF OTHER DISPERSION COEFFICIENTS TO BE TESTED

The stability selection algorithm and the dispersion calculation technique currently used within the Single Source Model will henceforth be referred to as the Pasquill-Turner method. During the next three parts of this section we shall discuss three other methods: (1) Smith-Singer, (2) Gifford-Briggs and (3) F. B. Smith and the manner in which they were included in modified versions of the Single Source Model.

SMITH SINGER DISPERSION COEFFICIENTS

The Smith-Singer method for determining the horizontal and vertical dispersion coefficients is based upon a series of atmospheric diffusion experiments conducted over a period of 15 years at the Brookhaven National Laboratory. These included oil fog studies for an elevated source, monitoring of reactor emissions by A^{41} and low level uranine dye releases. The choice of a particular stability assignment (A, A2, B1, C or D) for a given hour is related to a subjective estimate of the lateral turbulence intensity determined from analogue wind direction recordings (Figure 5). A more quantitative explanation of the classification scheme shown in Figure 5 is presented below:

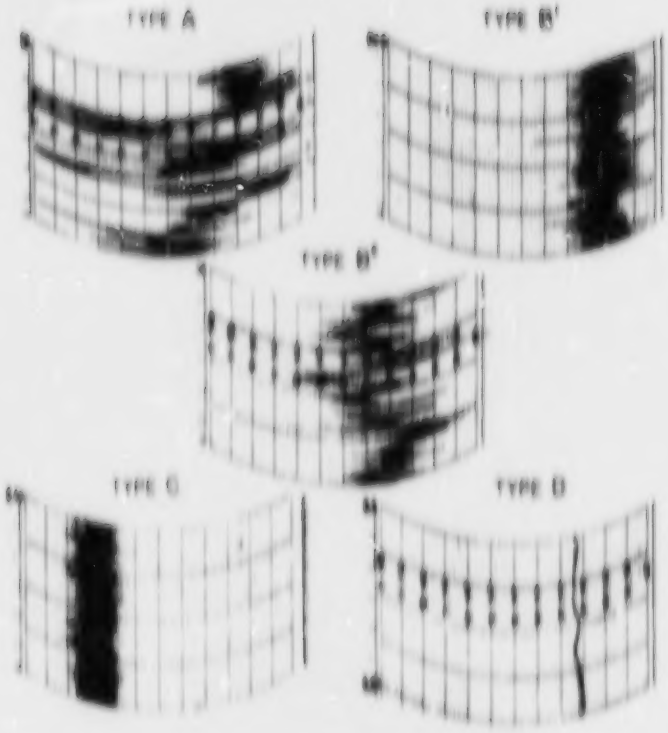

Figure 5. Wind direction trace types used to determine atmospheric stability by the Smith-Singer method[14]

A = fluctuations of the wind direction exceeding 90°;

B2 = fluctuations ranging from 40° to 90°;

B1 = similar to A and B2, with fluctuations confined to 15 and 45° limits;

C = distinguished by the unbroken solid core of the trace, through which a straight line can be drawn for the entire hour, without touching "open space"; and

D = the trace approximates a line - short-term fluctuations do not exceed 15°.

Power law expressions describing the variation of σ_y and σ_z with distance from the source are specified[12] in Table 3 for four of the five "gustiness classes" (B2, B1, C, and D).

Table 3. SMITH-SINGER POWER LAW PARAMETERS a,b FOR HORIZONTAL AND VERTICAL DISPERSION PARAMETERS $\sigma_{y,z} = ax^b$ WHERE x IS IN METERS[13]

	Stability class							
	B2		B1		C		D	
	a	b	a	b	a	b	a	b
σ_y	0.40	0.91	0.36	0.86	0.32	0.78	0.31	0.71
σ_z	0.41	0.91	0.33	0.86	0.22	0.78	0.06	0.71

The dispersion curves described by these parameters are shown in Figures 6 and 7.

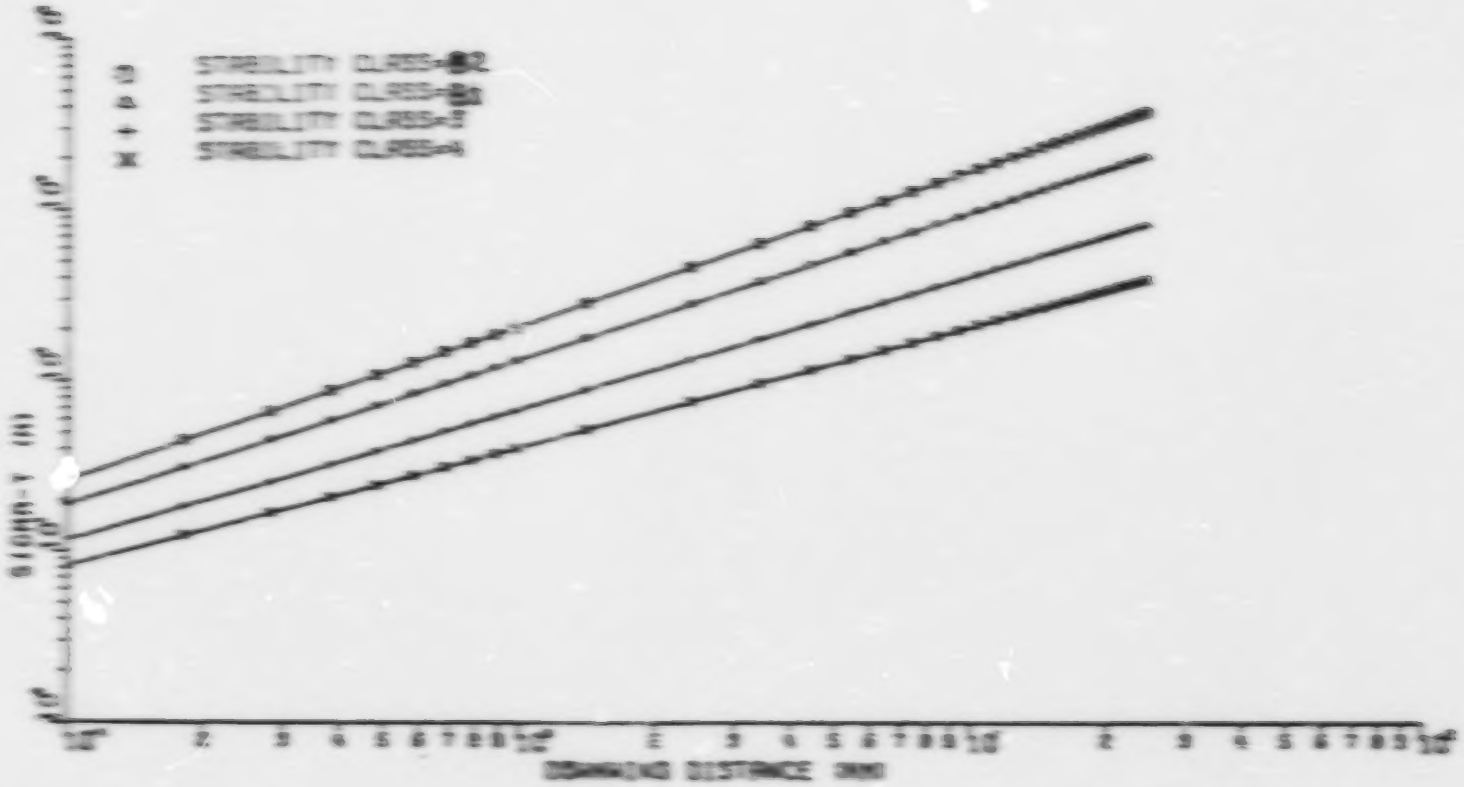

Figure 6. Variation of σ_y with distance for the Smith-Singer stability classes

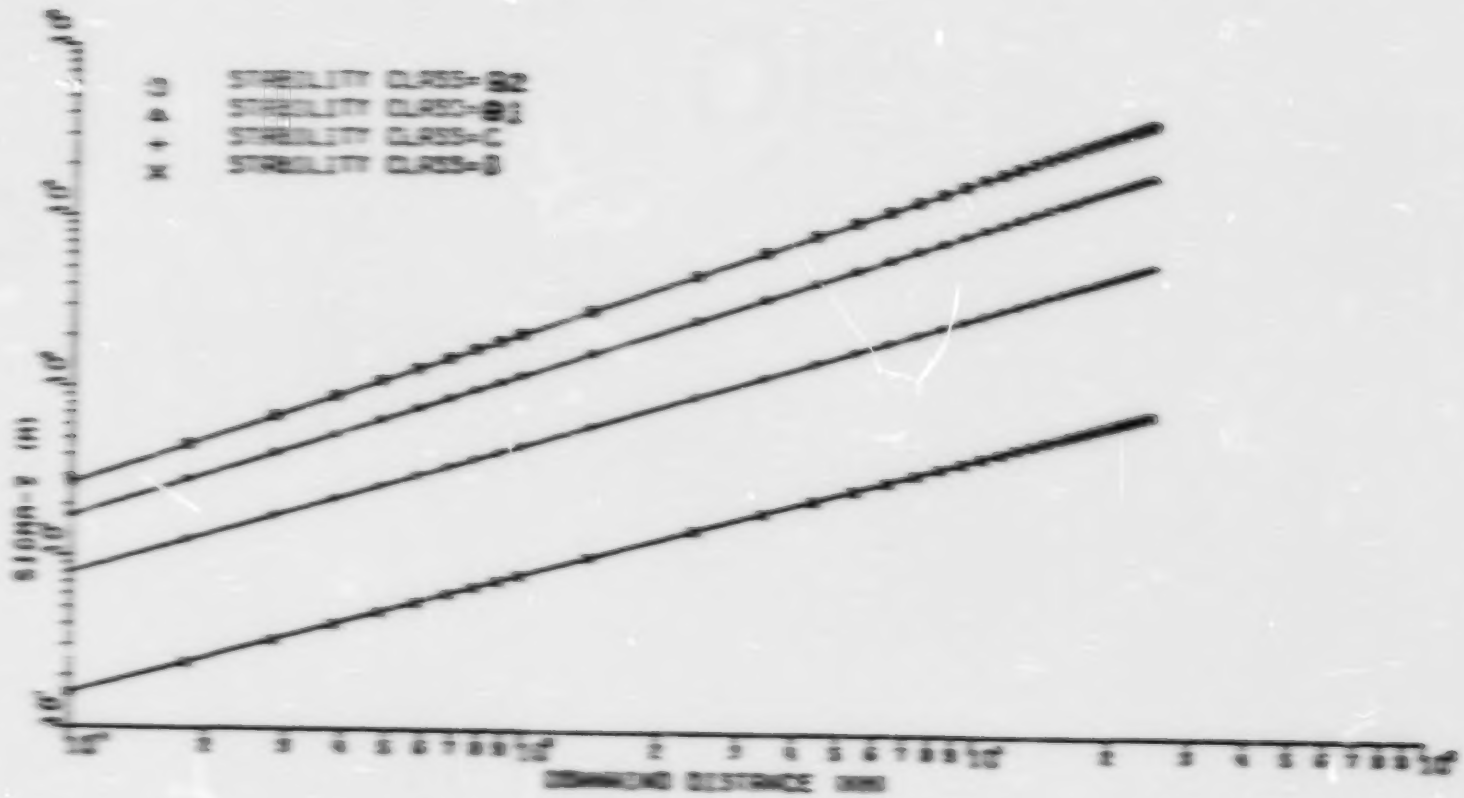

Figure 7. Variation of σ_z with distance for each of the Smith-Singer stability classes

No dispersion parameters are given for stability A since this condition is characterized by no organized horizontal wind flow so that the resultant ground level concentrations may only be described in a qualitative manner. Stability A cases were therefore not included in our validation studies to be described later in this report. As in the case of the Pasquill-Turner scheme the wind speed is assumed to increase with height according to a power law with the exponent n assigned the values 0.16, 0.25, 0.32, and 0.50 for atmospheric stabilities B2 through D.[13]

In the application of these dispersion curves to the prediction of concentrations downwind of large elevated point sources M.E. Smith calculates the effective stack height by use of the following formula presented in the ASME Guide[15] Second Edition, 1973:

$$h = h_s + 7.4 \left(\frac{F^{1/3} \, h_s^{2/3}}{u} \right) \qquad (6)$$

Since we were primarily interested in the comparison of different dispersion calculation methods we continued to employ the Briggs formulas, with Equation (2) used for stabilities B2, B1 and C and Equation (3) used for stability D. For power plant diffusion modeling Smith modifies his estimate of σ_y by adding a term to allow for the presence of directional wind shear:

$$\sigma_y = a x^b + x \tan \phi \qquad (7)$$

where ϕ = wind direction change

Since no rule is given for the selection of ϕ as a function of stability or plume height, the term was not included in our analysis. Had the term been included, it would have effectively lowered the predictions of ground level air concentrations especially for the more stable conditions.

GIFFORD-BRIGGS DISPERSION COEFFICIENTS

A method for the determination of plume standard deviations has recently been developed by Briggs[16] using a wide range of experimental data including the TVA and Prairie Grass measurements mentioned earlier. The selection of an appropriate stability class is called out according to the Pasquill-Turner method but the corresponding curves for σ_y and σ_z are chosen to represent a wider range of source elevations and source-receptor distances. Analytical expressions for σ_y and σ_z applicable to rural areas are given in Table 4. The utilization of the Gifford-Briggs method in the Single Source Model required only that the dispersion calculation subroutine be modified. The plume rise and the wind profile equations were left unchanged.

Table 4. VARIATION OF σ_y AND σ_z WITH DISTANCE x (METERS) FOR RURAL AREAS

Stability	σ_y (meters)	σ_z (meters)
A	$0.22x/\sqrt{1 + 0.0001x}$	$0.20x$
B	$0.16x/\sqrt{1 + 0.0001x}$	$0.12x$
C	$0.11x/\sqrt{1 + 0.0001x}$	$0.080x/\sqrt{1 + 0.0002x}$
D	$0.080x/\sqrt{1 + 0.0001x}$	$0.056x/\sqrt{1 + 0.0015x}$
E	$0.056x/\sqrt{1 + 0.0001x}$	$0.032x/(1 + 0.0003x)$
F	$0.040x/\sqrt{1 + 0.0001x}$	$0.016x/(1 + 0.0003x)$

F.B. SMITH DISPERSION COEFFICIENTS

Recently the Pasquill-Turner scheme for stability classification for vertical dispersion coefficients has been modified and extended by Pasquill's colleague, F.B. Smith,[17] to include the effect of surface

roughness and provide for the fractional assignment of stability classes. This latter development was especially significant since the variation of ground level air concentration with stability class can be an order of magnitude or more.

The scheme utilizes numerical solutions of the diffusion equation up to 100 km downwind with profiles of wind, u(z), and diffusivity, (K(z)), suggested by actual measurements in unstable, neutral and stable conditions. The horizontal dispersion coefficients are chosen to be the same as the Pasquill-Turner. The reason for this is that F. B. Smith does not recommend any specific σ_y curve, but rather advises the use of wind fluctuation data, with an adjustment for downwind distance. At larger distances, this adjustment makes $\sigma_y \propto x^{1/2}$ where x is downwind distance. Since the required wind fluctuation data are not available, the Pasquill-Turner σ_y data were used. It should be pointed out, however, that the Pasquill-Turner curves show σ_y to be approximately proportional to $x^{0.9}$ at all distances, and not $x^{1/2}$. The method for fractional stability assignment is illustrated in Figure 8. F.B. Smith presented Figure 9 as a guide for choosing a value for incoming solar radiation as a function of solar elevation angle. He recommends that this value be multiplied by an appropriate factor to account for the presence of cloud cover (see Table 5).

Table 5. MULTIPLICATION FACTORS FOR INCOMING SOLAR RADIATION INTENSITY FOR DIFFERENT AMOUNTS OF CLOUD COVER

Cloud Amount (eighths)	Multiplier
0	1.07
1	0.99
2	0.91
3	0.78
4	0.72
5	0.67
6	0.59
7	0.45
8	0.21

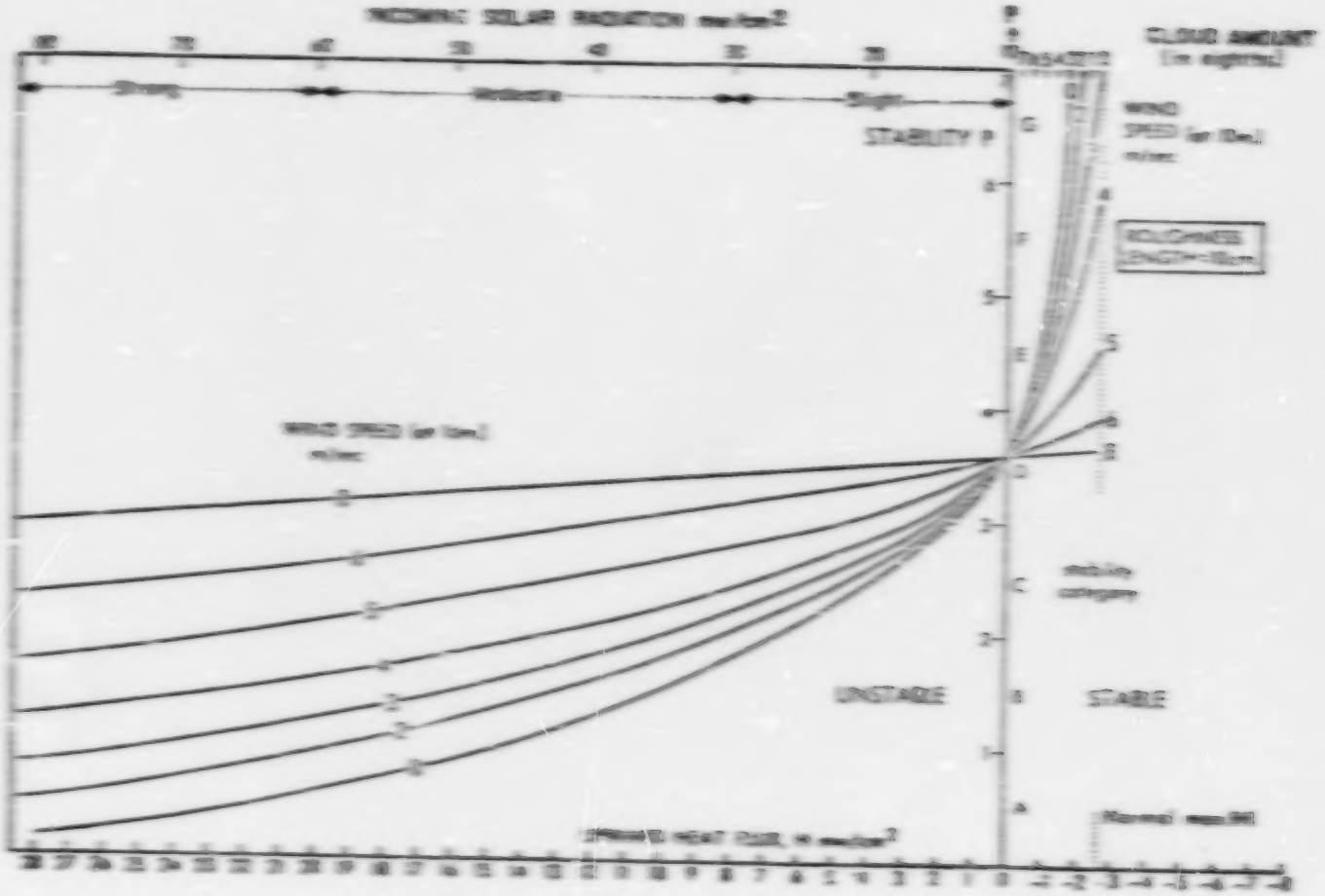

Figure 8. F.B. Smith scheme for assignment of fractional stability classes[17]

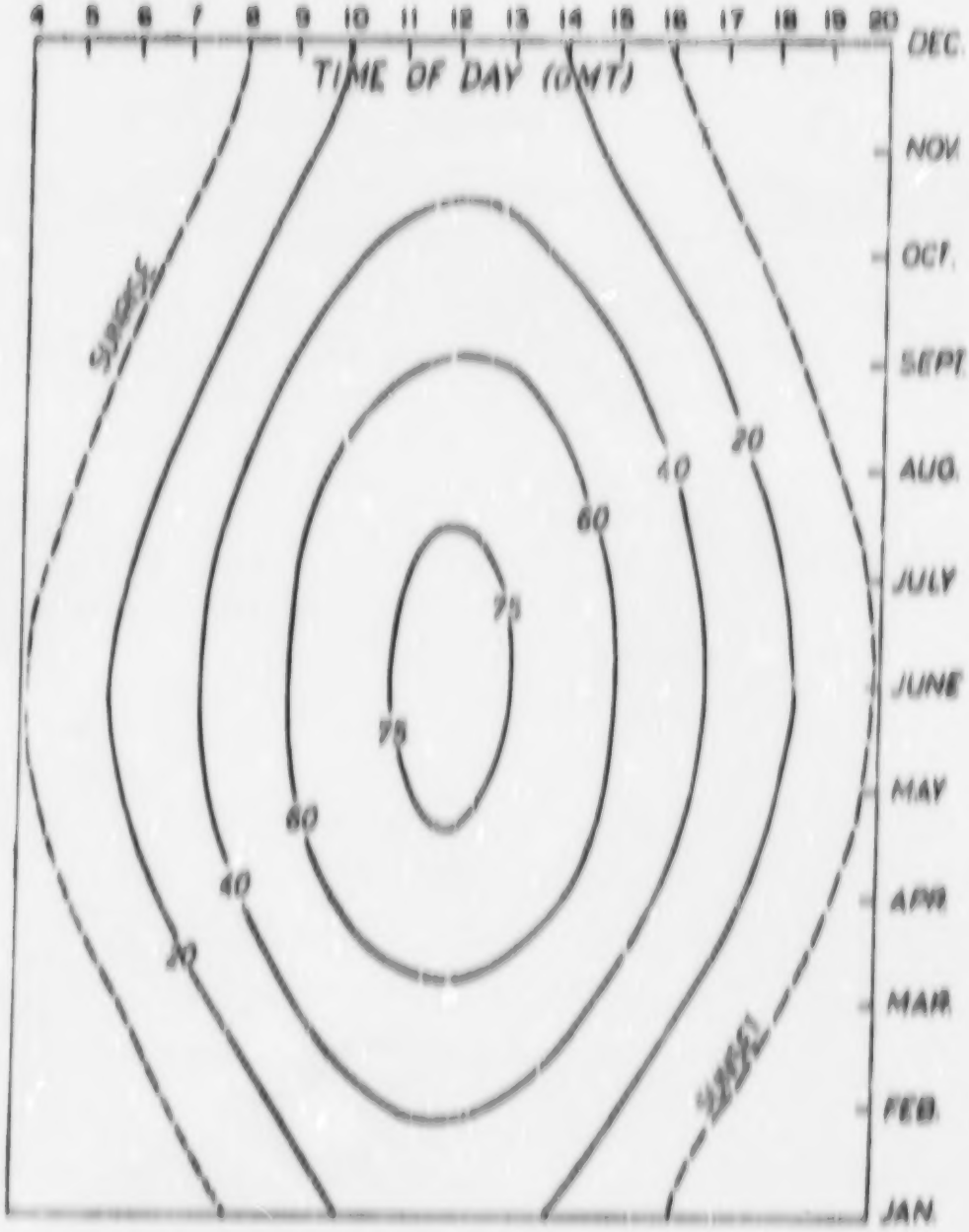

Figure 9. Incoming solar radiation (mW/cm^2) measured at Cambridge, England on a cloudless day[17]

To obtain a relationship between solar angle and incident solar radiation, we sought to describe the data presented in Figure 9 for Cambridge, England in terms of the following equation:[18]

$$I = \frac{J_0}{r^2} a^{\sec\theta} \cos\theta \qquad (8)$$

where I = solar radiation intensity

J_0 = 135.3 milliwatts/cm^2

a = transmission factor

θ = solar zenith angle (90° - solar elevation angle)

r = "radius vector" of earths orbit (≈ 1)

For a specific latitude and longitude the angle θ may be determined based upon the time zone classification, hour of the day (standard time) and day of the year. When the data were analysed it was found that the diurnal and seasonal variation of the radiation intensity, I, could not be reproduced by use of a constant transmission factor a. The best fit was obtained for the following variation of the transmission factor, a, with zenith angle θ.

$$a = 0.57 + 0.0045\,\theta \qquad (9)$$

where θ is measured in degrees. The fitted solar radiation intensity as a function of zenith angle is shown in Figure 10.

With the relationships given by Equations (8) and (9) the fractional stability index, F, may be determined from the curves shown in Figure 8 once the windspeed and cloud cover have been specified. In his article F. B. Smith identifies a F value of 3.6 with a D stability index (i.e., stability 4) which would have been determined according to the Turner scheme presented in Appendix A. The relationship between the fractional stability F and the Turner stability S_T should then be given by

$$S_T = (F + 0.4) \text{ rounded} \qquad (10)$$

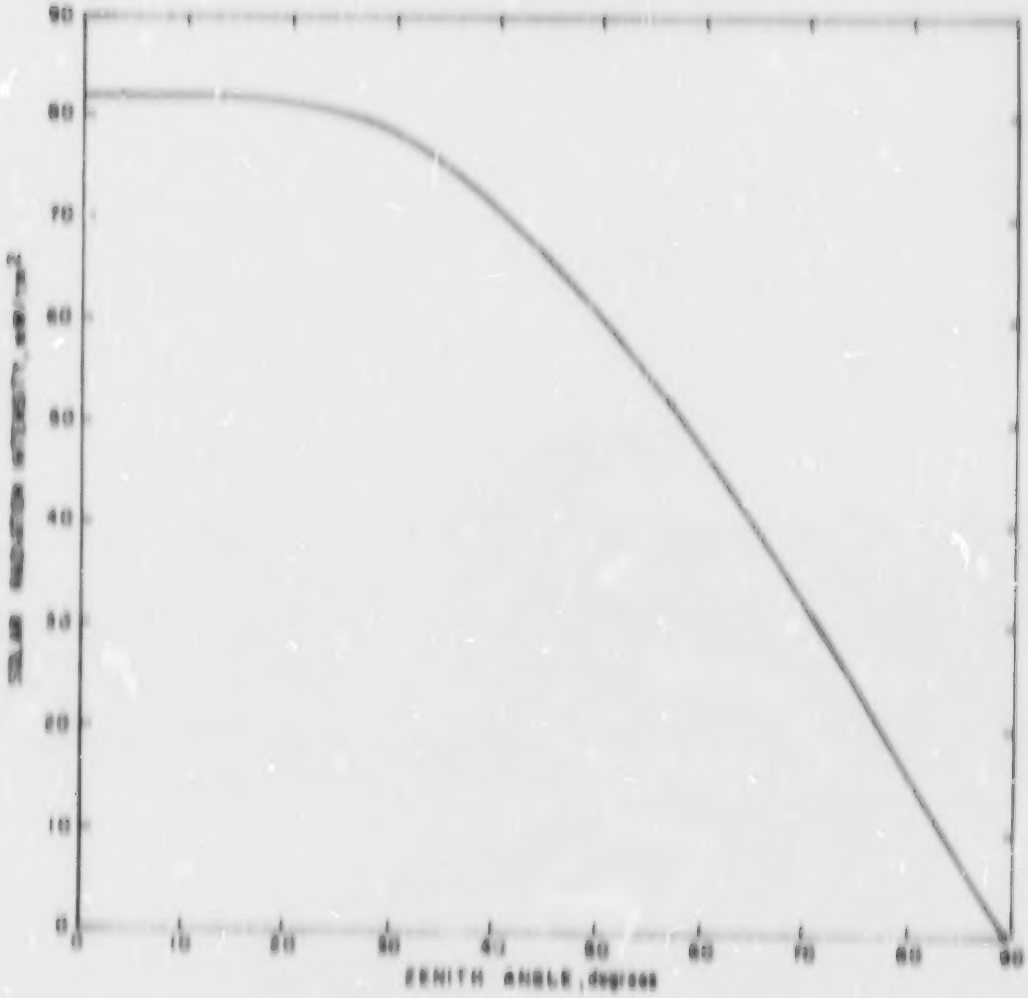

Figure 10. Solar radiation intensity as a function of zenith angle. Relationship based upon data presented in Figure 9

To determine the validity of this assumption we carried out a polynomial fit to the curves given in Figure 8 so that, based upon the solar elevation angle, cloud cover and wind speed, a comparison between the F. B. Smith and Turner assignment schemes could be made for a wide range of meteorological configurations. Based upon this comparison we found that the Turner stability class assignment was higher during the middle part of the day, especially during the summer months when the difference could be greater than an entire stability class. The polynomial fits used for this comparison formed the basis of the fractional stability of the Single Source Model Preprocessor Program which is presented in Appendix B.

Once the stability parameter P has been selected the corresponding vertical dispersion coefficient σ_z is determined for a particular downwind distance x by use of the curves presented in Figures 11 and 12. These results have been fitted by R. P. Hosker[19] to analytical expressions of the form

$$\sigma_z(x) = \frac{a_1 x^{b_1}}{1 + a_2 x^{b_2}} \qquad (11)$$

A list of the numerical values of the parameters used in Equation (11) is given in Table 6.

Table 6. FIT PARAMETERS FOR DISPERSION COEFFICIENTS

Stability category	a_1	b_1	a_2	b_2
A (P = 0.6)	0.117	1.06	5.38×10^{-4}	0.815
B (P = 1.6)	0.130	0.950	6.52×10^{-4}	0.750
C (P = 2.6)	0.112	0.920	9.05×10^{-4}	0.718
D (P = 3.6)	0.098	0.889	1.35×10^{-3}	0.688
E (P = 4.6)	0.0609	0.895	1.96×10^{-3}	0.684
F (P = 5.6)	0.0638	0.783	1.36×10^{-3}	0.672

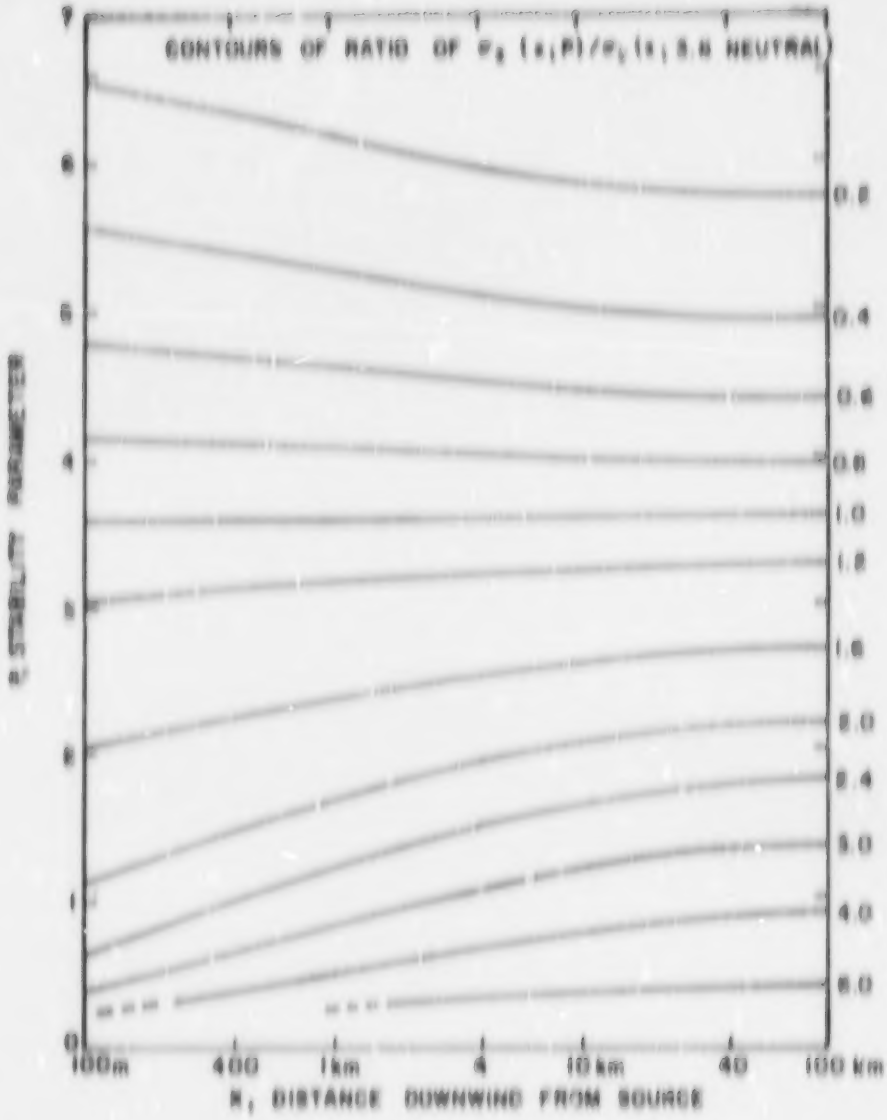

Figure 11. Variation with distance of the vertical dispersion parameter σ_z (normalised with respect to the neutral stability value) for different values of P[7]

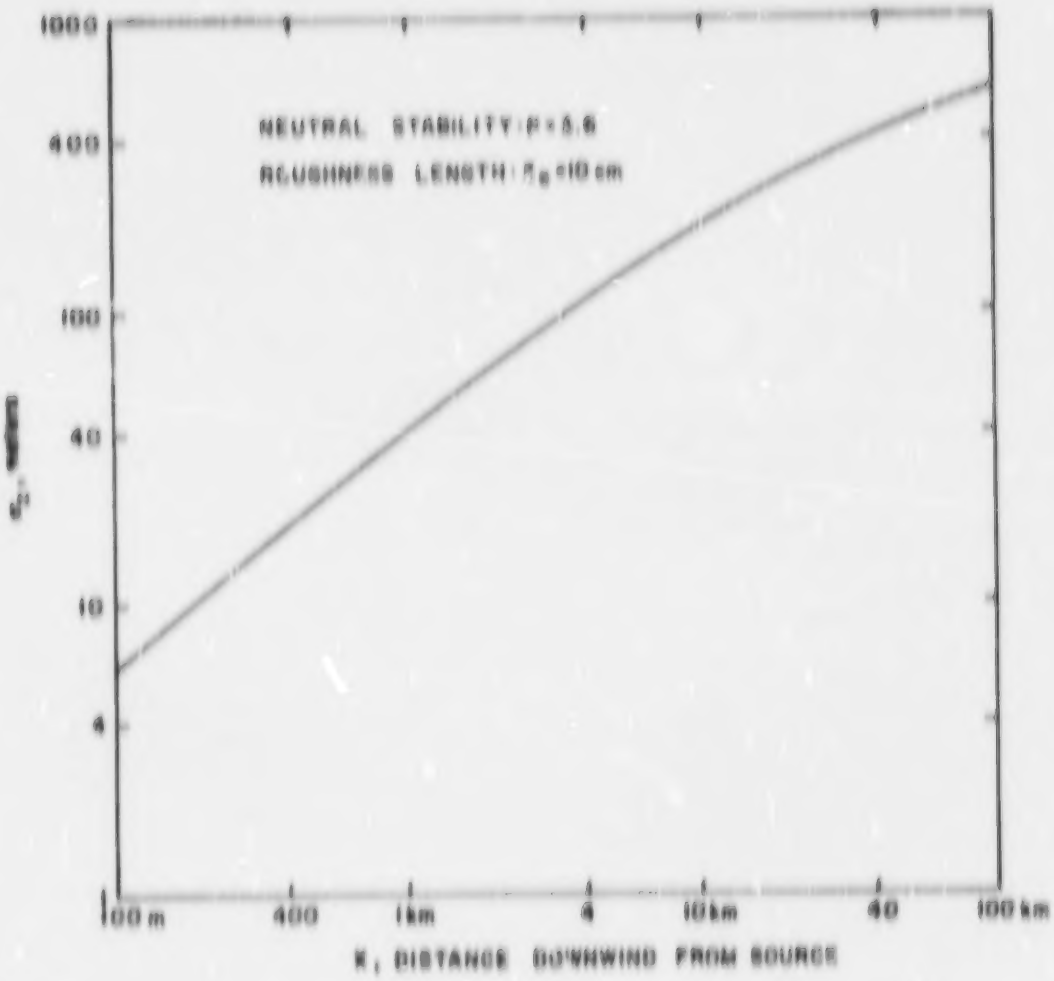

Figure 12. Variation of σ_θ with distance for stability D (P = 3.6)[1]

According to the F.B. Smith method the dispersion curves may be modified to account for the effect of surface roughness z_0. These correction factors are shown in Figure 13. As parameterized by Hosker,[19] this correction factor $F(z_0, x)$ takes the following forms:

$$F(z_0,x) = \ln \left\{ c_1 x^{d_1} \left[1 + \left(c_2 x^{d_2} \right)^{-1} \right] \right\}, \quad z_0 > 10 \text{ cm} \qquad (12)$$

$$= \ln \left\{ c_1 x^{d_1} \left[1 + c_2 x^{d_2} \right]^{-1} \right\}, \quad z_0 < 10 \text{ cm} \qquad (13)$$

The corrected dispersion coefficient $\sigma_z(z_0, x)$ may be written as

$$\sigma_z(z_0,x) = F(z_0,x)\ \sigma(10 \text{ cm}, x) \qquad (14)$$

where the $\sigma(10 \text{ cm}, x)$ are the σ_z values given by the curves in Figures 11 and 12. The parameters required to evaluate Equations (12a) and (12b) are presented in Table 7.

Table 7. COEFFICIENTS OF THE ROUGHNESS CORRECTION FACTOR USED IN CALCULATING $\sigma_z(x)$ FOR VARIOUS ROUGHNESS LENGTHS (x IS GIVEN IN METERS)

Roughness length	c_1	d_1	c_2	d_2
1 cm	1.56	0.0480	6.25×10^{-4}	0.45
4 cm	2.02	0.0269	7.76×10^{-4}	0.37
40 cm	5.16	-0.098	18.6	-0.225
100 cm	7.37	-0.0957	4.29×10^{3}	-0.60
400 cm	11.7	-0.128	4.49×10^{4}	-0.78

In Section IV of this report we will describe three types of model validation studies based upon the F.B. Smith dispersion coefficients. The first test will combine the Turner stability class assignment scheme with the F.B. Smith dispersion curves for the point stabilities (A, B, C, D, E and F). The second test will involve the calculation and use of fractional

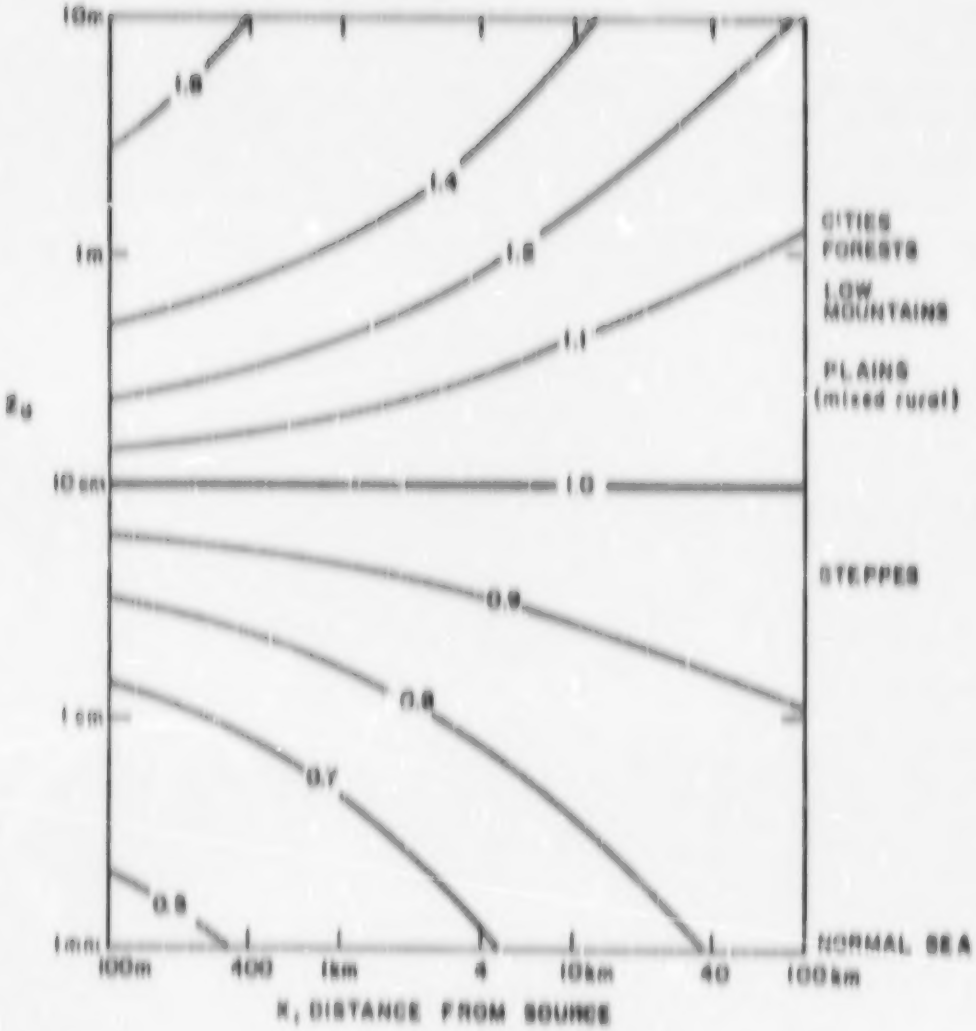

Figure 13. Contours of the vertical dispersion coefficient correction factor $F(z_0,x)$

stabilities. Finally the effect of incorporating surface roughness will be investigated.

COMPARISON OF THE DISPERSION COEFFICIENTS

A comparison of the dispersion curves we have just discussed will prove useful in our analysis of the model validation results which will be presented in Section IV. In Figures 14(a) through (f), vertical dispersion coefficients according to Briggs, F.B. Smith, and Pasquill-Turner are plotted as a function of downwind distance for stabilities A through F. The following observations may be made based upon an examination of these curves:

1. The Briggs and Pasquill-Turner curves are quite close to one another except in the case of stability A.

2. The F.B. Smith vertical dispersion curve falls below the other two curves for stabilities A, B and C and above the other curves for stabilities D, E and F.

3. The worst agreement between all three of the curves is seen for stability A with the best agreement for stabilities D, E and F.

In Figures 15(a) through (f) we have plotted the horizontal dispersion curves according to Briggs and Pasquill-Turner by stability class. The Pasquill-Turner horizontal dispersion curves are used in conjunction with the F.B. Smith vertical dispersion curves, so that no F.B. Smith horizontal curves have been presented. An obvious feature of these plots is that the Briggs and Pasquill curves are virtually identical. The horizontal and vertical dispersion curves according to Smith-Singer were presented in Figures 6 and 7 for the four Smith-Singer stability classes B2, B1, C and D. The most striking feature of these plots is the identical slope for σ_z and σ_y curves for the same stability. Finally the effect of surface roughness upon the F. B. Smith vertical dispersion curves is illustrated in Figures 16(a) through (f).

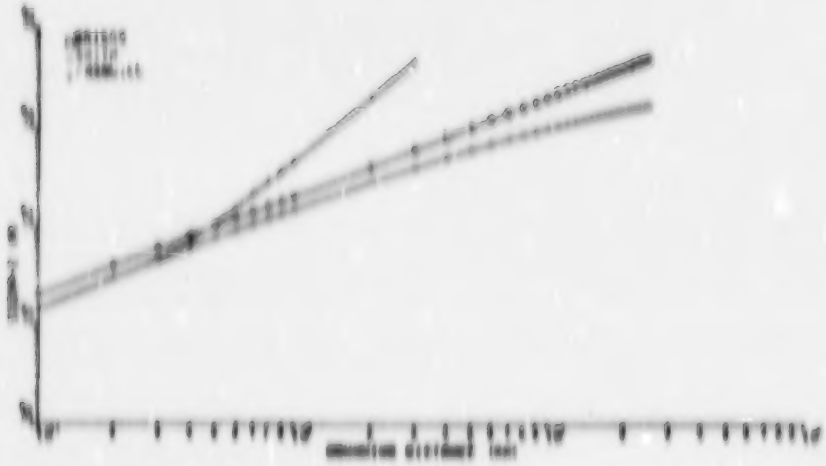

Figure 14a. Vertical dispersion coefficient as a function of downwind distance for Stability Class A according to Briggs, F.B. Smith and Pasquill-Turner

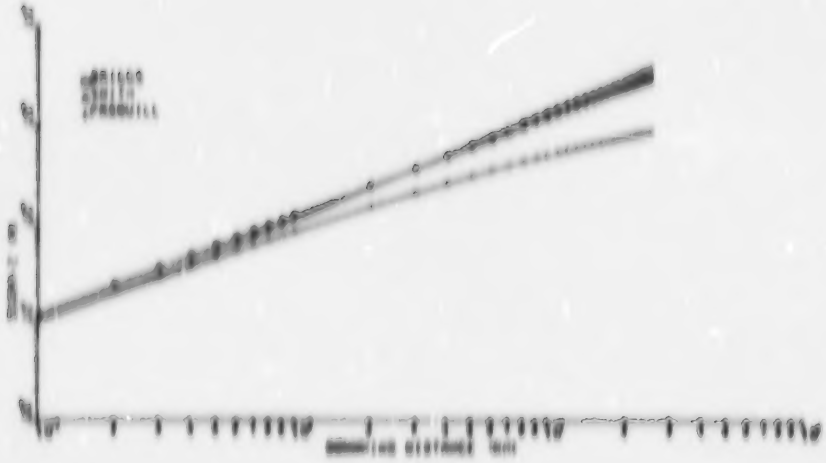

Figure 14b. Vertical dispersion coefficient as a function of downwind distance for Stability Class B according to Briggs, F.B. Smith and Pasquill-Turner

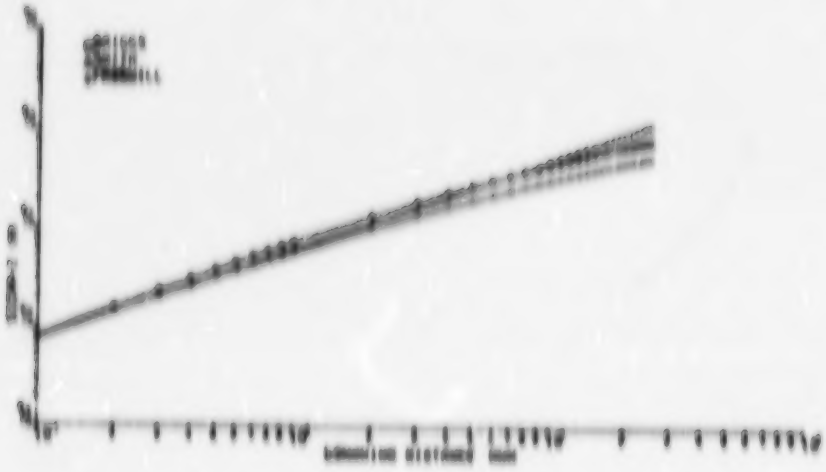

Figure 14c. Vertical dispersion coefficient as a function of downwind distance for Stability Class C according to Briggs, F.B. Smith and Pasquill-Turner

Figure 14d. Vertical dispersion coefficient as a function of downwind distance for Stability Class D according to Briggs, F.B. Smith and Pasquill-Turner

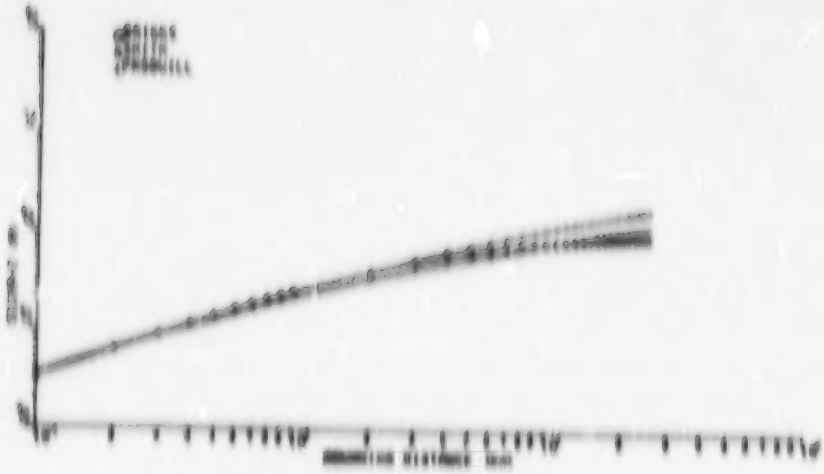

Figure 14e. Vertical dispersion coefficient as a function of downwind distance for Stability Class E accordings to Briggs, F.B. Smith and Pasquill-Turner

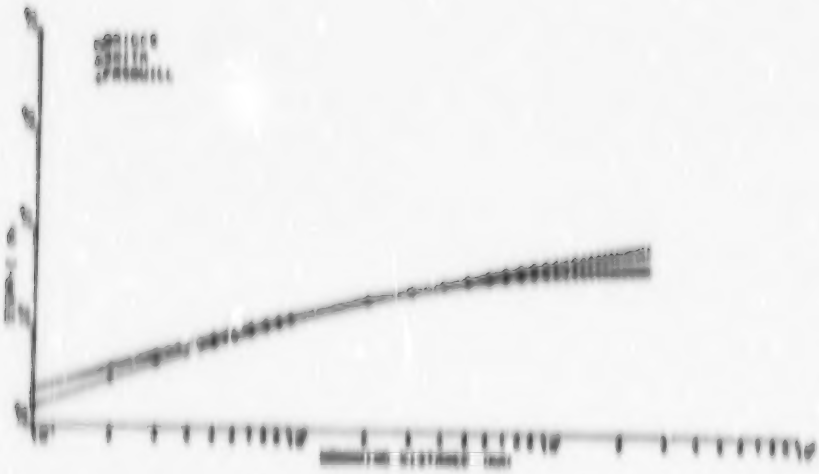

Figure 14f. Vertical dispersion coefficient as a function of downwind distance for Stability Class F according to Briggs, F.B. Smith and Pasquill-Turner

Figure 15a. Horizontal dispersion coefficient as a function of downwind distance for Stability Class A according to Briggs and Pasquill-Turner

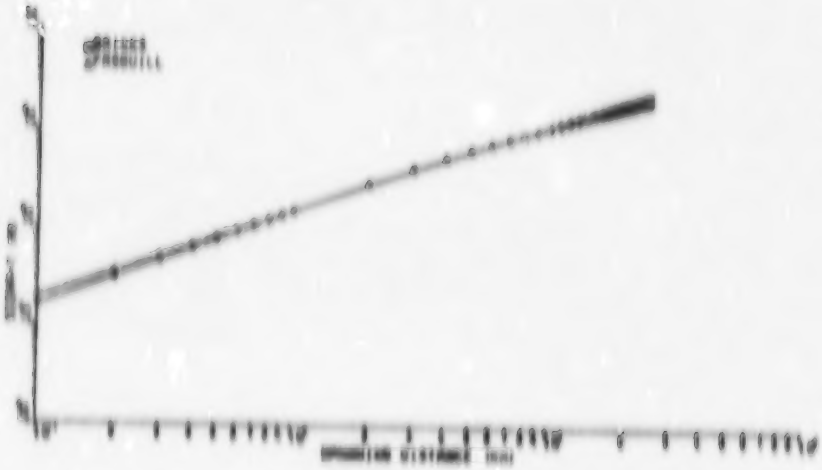

Figure 15b. Horizontal dispersion coefficient as a function of downwind distance for Stability Class B according to Briggs and Pasquill-Turner

Figure 15c. Horizontal dispersion coefficient as a function of downwind distance for Stability Class C according to Briggs and Pasquill-Turner

Figure 15d. Horizontal dispersion coefficient as a function of downwind distance for Stability Class D according to Briggs and Pasquill-Turner

Figure 15e. Horizontal dispersion coefficient as a function of downwind distance for Stability Class E according to Briggs and Pasquill-Turner

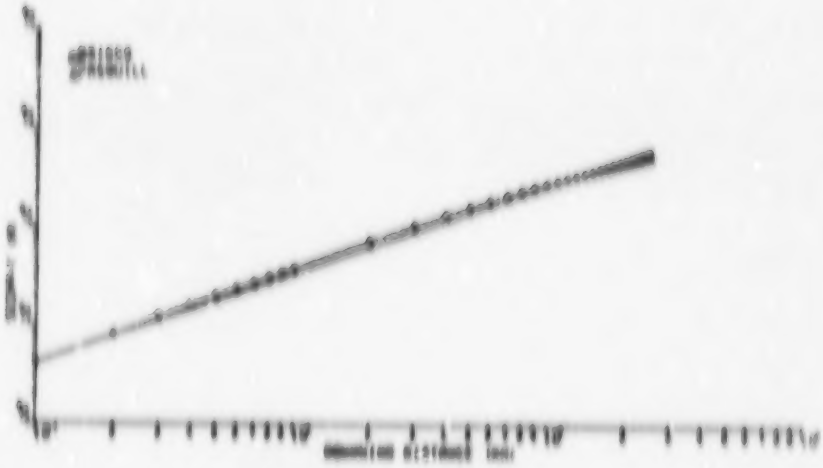

Figure 15f. Horizontal dispersion coefficient as a function of downwind distance for Stability Class F according to Briggs and Pasquill-Turner

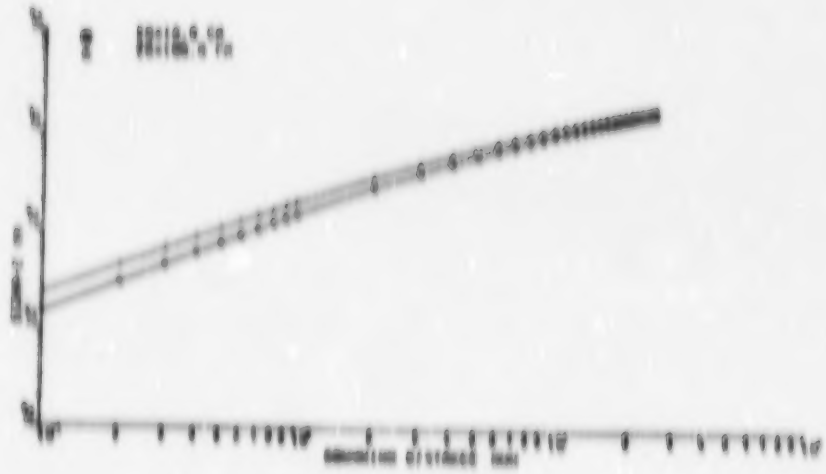

Figure 16a. Vertical dispersion coefficient as a function of downwind distance for Stability Class A and surface roughness of 10 cm and 100 cm according to F.B. Smith

Figure 16b. Vertical dispersion coefficient as a function of downwind distance for Stability Class B and surface roughness of 10 cm and 100 cm according to F.B. Smith

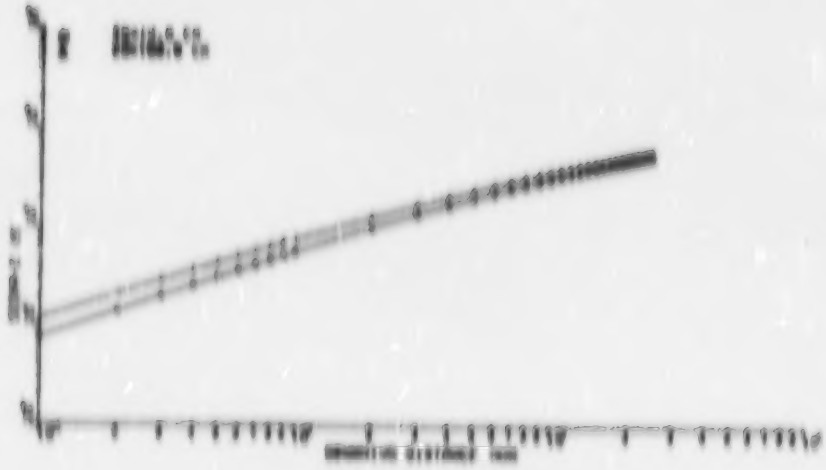

Figure 16c. Vertical dispersion coefficient as a function of downwind distance for Stability Class C and surface roughness of 10 cm and 100 cm according to F.B. Smith

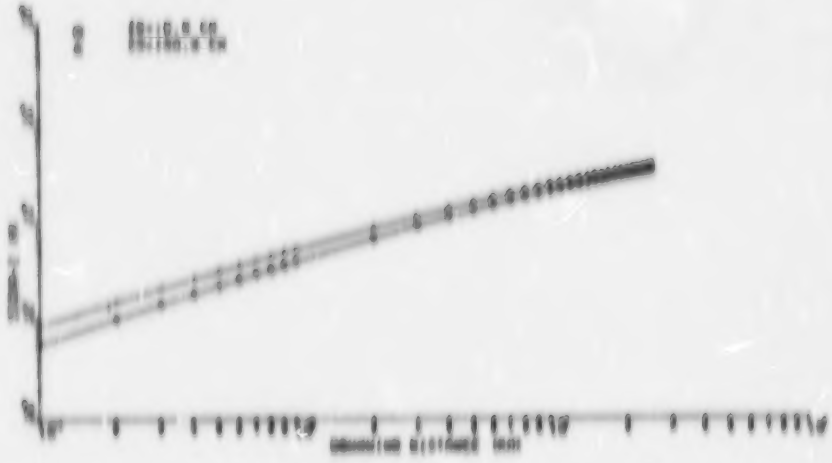

Figure 16d. Vertical dispersion coefficient as a function of downwind distance for Stability Class C and surface roughnesses of 10 cm and 100 cm according to F.B. Smith

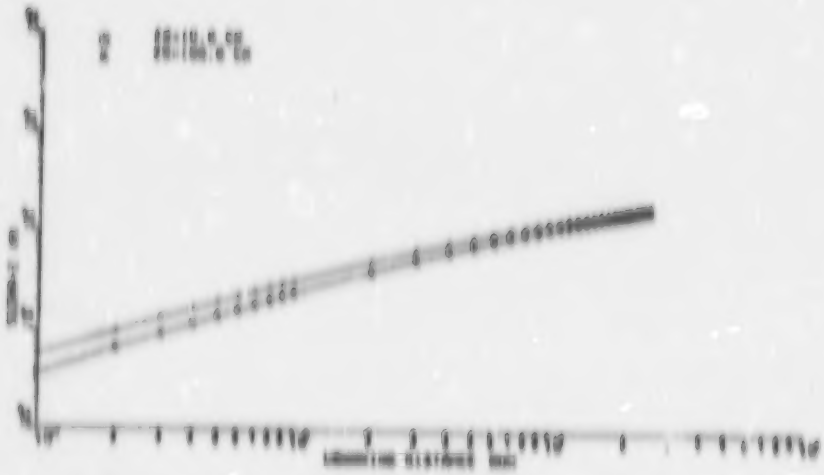

Figure 16e. Vertical dispersion coefficient as a function of downwind distance for Stability Class E and surface roughnesses of 10 cm and 100 cm according to F.B. Smith

Figure 16f. Vertical dispersion coefficient as a function of downwind distance for Stability Class F and surface roughnesses of 10 cm and 100 cm according to F.B. Smith

DISCUSSION OF THE PROCEDURE FOR VARYING THE PLUME RISE

Another objective of this study was to determine whether the requirement of a constant stack gas exit velocity was adversely affecting the model predictions. To study the effect of a variable stack gas exit velocity, the hourly velocity was calculated according to the following expression:

$$v_h = v_a \frac{f_h}{f_a}$$

where v_a = stack gas exit velocity obtained from form FPC-67

f_h = hourly fuel consumption for all boilers feeding into the stack

f_a = average hourly fuel consumption for all boilers feeding into the stack

SECTION III

SITE AND DATA BASE DESCRIPTIONS FOR MODEL IMPROVEMENT STUDY

In this section we shall describe the site characteristics, SO_2 monitoring program and meteorological data base for the two power plants included in the model improvement study. Each topic will be covered on a plant-by-plant basis. Much of this material has already been covered in these previous EPA reports but is presented again for the sake of completeness. Also the description of the meteorological data base is somewhat different for this study since for a large number of cases local wind speed and wind direction data were used for model input as well as for background subtraction.

At the outset of this study we planned to include the J.H. Stuart Plant in our test of the Smith-Singer Dispersion Coefficients, but we subsequently found that the angular resolution of the local wind direction data did not permit a meaningful comparison between measurements and model predictions. The Philo Power Plant was also excluded from our analysis of model improvements due to the complications of terrain mentioned in Section I. The tests of different dispersion calculation methods were, therefore, carried out for the Canal and Muskingum River Plants.

CANAL PLANT

Site Description

The Canal Plant is located on the south side of the Cape Cod Canal about 1.6 kilometers from the entrance on Cape Cod Bay (Figure 17). The

Figure 17. Map of eastern Massachusetts and Rhode Island showing locations of the Canal Plant. Meteorological observations were used from Quonset Point Naval Air Station and Chatham.

surrounding terrain is gently rolling with elevations generally below 60 meters above mean sea level. The highest elevations in the area are about 90 meters above sea level in the western end of the Cape. Most of the area is covered with scrub pine forests and low vegetation.

Data for the study were collected in 1971. During that year, the plant consisted of a single oil-fired unit with a generating capacity of 560 megawatts. The top of the stack was about 91 meters above grade and 5.6 meters in diameter. The main power plant structure to the north of the stack totally enclosed the turbine generator and boiler. The roofs of the turbine and boiler rooms were about 30 meters and 39 meters above grade respectively. Stack and boiler data are given in Table 8. The 1971 monthly percent sulfur content of the fuel used at the Canal Plant is given in Table 9.

Table 8. PLANT CHARACTERISTICS

Characteristic	Plant		
	Canal	Muskingum	
	Stack 1	Stack 1	Stack 2
Stack height, m	91	251	251
Diameter, m	5.6	7.6	6.7
Velocity, m/sec	-	28.5	24.8
Temperature, °F	-	430	425
Number of boilers per stack	1	4	1
Maximum generating capacity per stack, MW	560	876	591
Average per stack, MW	-	748	487
Plant total, MW	560	1467	
Plant average, MW	-	1235	

Table 9. MONTHLY PERCENT SULFUR CONTENT OF FUEL

Month	Canal	Muskingum
January	2.0	4.9
February	1.9	4.8
March	2.1	4.8
April	1.9	4.5
May	2.1	4.7
June	2.1	5.0
July	2.1	4.7
August	2.0	4.7
September	1.9	4.3
October	0.9	4.6
November	1.0	4.5
December	0.9	4.4

Overview of Canal Plant Monitoring Program

SO_2 concentrations are measured at four locations on a continuous basis with Ultragas SO_2 Analyzers manufactured in Germany by H. Westhoff. These instruments measure sulfur dioxide by the increase in conductivity of an acidified hydrogen peroxide solution and have a full scale reading of 0.4 ppm. The instruments do not conform to the reference method for sulfur dioxide or to any of the specified equivalent methods. They have, however, been extensively studied and one comparison noted a correlation coefficient of 0.99 with the West-Gaeke method. The instruments used provide a continuous real-time chart trace and a tape printout giving date, time, and average concentration over consecutive 30 minutes. The sensitivity of the instrument in combination with the chart recorder is approximately 0.005 ppm. The locations of the SO_2 monitors with respect to the Canal Plant are given in Figure 18 and Table 10.

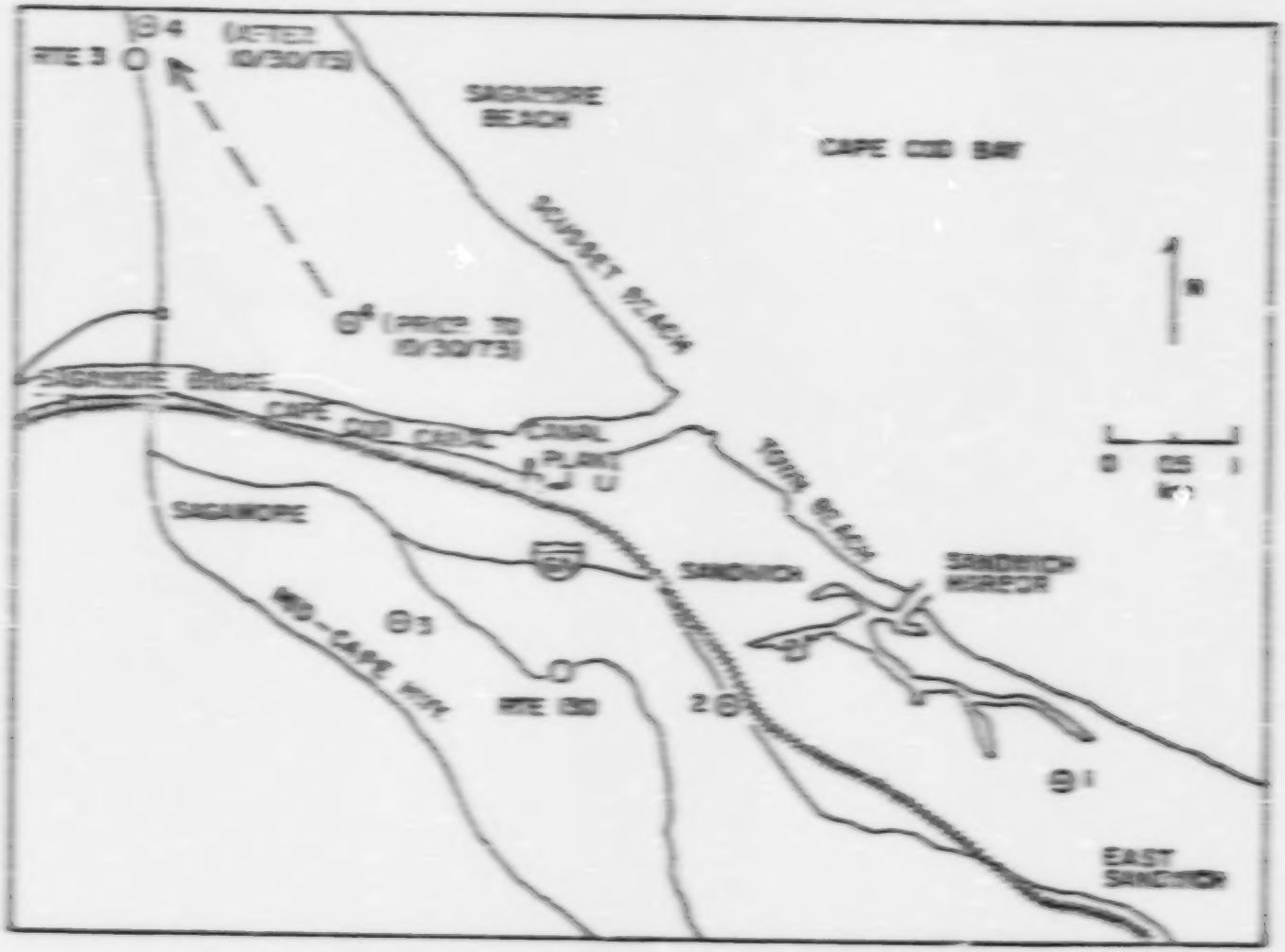

Figure 18. Sketch of the Canal Plant area showing the locations of the four automatic SO_2 stations by the symbol ⊖

Table 10. SULFUR DIOXIDE MONITORING STATIONS FOR THE CANAL AND MUSKINGUM PLANTS

Plant	Station No.	Station Name	Distance, km	Heading, degrees	Elevation above stack base, m
Canal	1		4.7	119	10
	2		2.3	138	4
	3		1.4	224	40
	4		2.0	312	20
Muskingum	1	Beverly	5.3	150	66
	2	Hackney	4.3	40	82
	3	Rich Valley	8.3	35	101
	4	Caldwell	19.6	35	128
	*	Top of stacks	*	*	151

Meteorological Data for Canal Plant

Bendix-Friez Aerovanes are used to provide local wind speed and direction data. Through July 1971, the principal source of wind data was the Aerovane mounted on a 12.2 meter mast located on the 38.8 meter boiler-room roof. Since July 1971, wind data are obtained from a second Aerovane installed on a 44 meter tower near the top of Telegraph Hill approximately 5 kilometers south-southeast of the Canal Plant. This hourly wind data was used to define upwind receptor locations for calculation of hourly background concentrations. A station was considered to be a background receptor if it were located outside the boundaries of a 90 degree sector centered about the wind flow vector. The concentrations for these background stations are then averaged and subtracted from the hourly concentration at all stations. Any resultant negative concentrations were set equal to zero. The on-site wind speed, wind direction and ambient temperature data were also input to the Single Source Model after proper conversion to a wind measurement height of 7 meters. These stability dependent wind speed corrections, which were discussed in Section II, were based upon hourly atmospheric stabilities derived from a Single

Source Model Preprocessor run using surface meteorological data for 1971 collected at Quonset Point Naval Air Station. Hourly mixing heights for 1971 were based upon surface data from Quonset Point, Rhode Island and upper air observations taken at Chatham, Massachusetts. In this way a "hybrid" Preprocessor output file was generated containing on-site wind speed, wind direction and temperature measurements and nonlocal stability and mixing height assignments.

MUSKINGUM PLANT

Site Description

The Muskingum Plant is located in southeastern Ohio on the Muskingum River about 6 kilometers northwest of the town of Beverly. Figure 19 indicates the location of the plant, the SO_2 monitoring sites, and the surrounding towns. The plant is in the river valley about 500 meters from the valley walls which rise about 75 meters above the valley floor. The two 251 meter stacks are 640 meters apart and extend about 185 meters above the surrounding terrain. During 1973 the plant consisted of five coal-fired units with a total capacity of 1667 megawatts (Table 8). Percent sulfur content of the fuel for 1973 is given in Table 9.

Overview of the Muskingum Monitoring Program

Four sulfur dioxide monitoring stations make up the monitoring network (Figure 19 and Table 10). Data were available from all stations for January 1 to November 21, 1973. During the entire year of 1973, Station 1 missed 57 days and the other three stations missed approximately 41 days. Instruments at Muskingum were Leeds & Northrup Company, Catalog No. 7860-SW, Aeroscan Air Quality Monitors. The sample was obtained by passing ambient air taken from 5 feet above ground level, through an absorption column along with an absorption solution. The sample analysis method was by electrolytic conductivity. Data were taken continuously and listed every hour. Each instrument was automatically zeroed once a day.

Figure 19. Sketch of the Muskingum Plant area showing locations of four automatic SO_2 monitoring stations

The manufacturer's performance accuracy specifications for this instrument are as follows. In a typical ambient atmosphere which includes the normal interfering gases, this instrument has:

- Zero drift = 2 percent of full scale per week
- Sensitivity drift < 1 percent of full scale per week
- Reproductibility < 1 percent of full scale
- Sensitivity = 0.01 ppm
- Recorder error < 0.5 percent of full scale
- Range = approximately 0 - 1 ppm

Meteorological Data for Muskingum Plant

There were two wind monitoring stations at the Muskingum Plant consisting of Bendix-Fries Aerovane wind speed and direction devices. One station was located 24 meters above ground at Beverly, and the other at the Hackney SO_2 monitoring station, where the wind monitors were also located 24 meters above ground. The data from Hackney was used in this study, as it was higher and common to more stations, but Beverly data was used when the Hackney system was not recording. On-site hourly wind direction data were used for the assignment of upwind receptor locations whose concentrations were then used in a background subtraction procedure identical to the one described for the Canal plant. Wind speeds at these two meteorological stations were adjusted to the 7 meter height by means of the stability dependent power law currently used in the Single Source Model and hourly stabilities based upon Huntington, West Virginia surface observations for 1973. A hybrid Preprocessor output file was then constructed using local wind direction and adjusted windspeed data in conjunction with ambient temperature and stability assignments from Huntington. Hourly mixing heights were based upon surface and upper air data both collected at Huntington. This particular combination of on-site and nonlocal meteorological data were used to test the Pasquill-Turner, Gifford-Briggs and F. B. Smith dispersion parameters at the Muskingum Plant. In our test of the F. B. Smith fractional stabilities, the Preprocessor program was modified to include a two-digit stability class.

For the test of the Smith-Singer dispersion coefficients, local values for wind direction, wind speed (uncorrected) and Smith-Singer stability class (1 - 6) were used with nonlocal values for ambient temperature and mixing height as input to the Single Source Model modified to include Smith-Singer dispersion coefficients and wind speed profile parameters.

SECTION IV

MODEL VALIDATION RESULTS

Our test of the different sets of dispersion coefficients described in Section II was based upon a comparison of cumulative frequency distributions of measured and predicted 1-hour SO_2 concentrations at the Canal and Muskingum Power Plants. The combinations of power plant sites, stability assignment algorithms, dispersion coefficients and meteorological data bases are presented in Table II along with the results of each model validation test and the numbers of the figures illustrating each test. The results of the variable plume rise test are also included in Table II.

The overall conclusion which may be reached based upon the examination of results presented in Table II is that the Pasquill-Turner dispersion coefficients and stability assignment algorithm yield the best agreement of the methods tested with the possible exception of the Gifford-Briggs dispersion coefficients. Although in the case of the Canal Plant the Gifford-Briggs coefficients gave slightly better agreement with measurements than the Pasquill-Turner curves, the two schemes worked equally well for the Muskingum Plant. This outcome is reasonable in light of the close agreement between the σ_z curves, except for stability A, for the two different methods (see Figures 15a through 15f).

The most surprising result of the study was the failure of the Smith-Singer dispersion coefficients and stability assignment scheme to predict the upper percentile or even the shape of the 1-hour concentration frequency distribution (see Figures 24a through 24e). One would expect these

coefficients to be better suited to the prediction of short-term SO_2 levels in the vicinity of power plants since they were based upon experiments involving the release of tracers from elevated sources. Since the criteria for selection of a given curve is somewhat qualitative, this may be a factor in their not giving a proper frequency distribution shape.

Since a major portion of our validation efforts involved the testing of the fractional stability scheme of F.B. Smith, we shall examine a number of reasons behind the resulting poor agreement with measured 1-hour SO_2 concentrations. Our first test of the F.B. Smith method involved point stability assignments according to Pasquill-Turner and the corresponding F.B. Smith Dispersion curves for stabilities A through F. Again it should be pointed out that only the F.B. Smith σ_z estimates were used in this model validation test. The Pasquill-Turner σ_y curves (see Figure 2), were used in conjunction with the F.B. Smith σ_z's. The results of this first validation exercise (Run Nos. 6 and 8) indicated a strong tendency for the F.B. Smith point stability dispersion curves to underpredict 1-hour SO_2 concentrations both for the Canal and Muskingum Plants. The only exception to this finding was the result for Muskingum Station 4 which showed slightly improved agreement over the Pasquill-Turner results (Run No. 2). The reason that this station did not follow the trend toward underprediction may have been its location 19.6 km from the plant. At this distance the largest concentrations should be observed during the more stable conditions (D, E and F). For these stability classes the F.B. Smith σ_z curves do not differ radically from the Pasquill-Turner curves (see Figures 1b through 1e). When a surface roughness of 100 cm, rather than the standard value of 10 cm, was used for calculation of the F.B. Smith σ_z curves the agreement between predicted and measured 1-hour SO_2 concentrations was somewhat better for the Canal Plant (Run No. 7), although the assumption of 100 cm surface roughness for this site is clearly unrealistic.

To determine whether the F. B. Smith vertical dispersion curves would yield better results when used in conjunction with the F. B. Smith stabilities described in Section II, we rewrote the Single Source Model

Preprocessor Program to include the fractional stability calculation techniques discussed in Section II. Minor modifications to the Single Source Model itself were made to provide for the interpolation of σ_y and σ_z values based upon the fractional stability assignment. A comparison of the Pasquill-Turner and F. B. Smith stabilities for three days in 1973 based upon Huntington, West Virginia surface meteorological data is presented in Table 12. Local windspeed and wind direction data for the Muskingum River Plant were not used in this calculation since the windspeed measurements were obtained at 24.2 m above the ground and not the 10 m height required for use in the F. B. Smith calculation. A stability dependent power law correction could have been used to convert the windspeed to the 10 m height except that the purpose of the exercise was to actually determine the fractional stability. Although the 7 m measurement height assumed for Huntington, W. Va. was not equal to the required 10 m height, the resulting error is negligible.

When the fractional stability versions of the Preprocessor Program and the Single Source Model were run for the Muskingum Plant, an overprediction occurred for stations 2, 3 and 4, compared to the substantial underprediction which resulted when the F. B. Smith dispersion coefficients were used in conjunction with the Pasquill-Turner point stability assignments. The generally lower stability index assignments based upon the F. B. Smith method have overcompensated for the smaller F. B. Smith σ_z values for the A, B and C stability classes. An example of the generally lower stability indices calculated by the F. B. Smith method is shown in Table 12. For the midday hours during the summer months the F. B. Smith stability indices can be more than one stability class lower than the corresponding Pasquill-Turner values.

The final objective of the model improvement study was to determine whether the incorporation of an hourly variation of a stack gas exit velocity, which is directly proportional to the fuel consumption rate, would improve model agreement with measured 1-hour SO_2 concentrations. The procedure for calculating hourly exit velocities was described in

Section II. Although the tests for the Canal and Muskingum River Plants showed no such improvement, the inclusion of a variable buoyancy flux in the model still may be desirable in the case of highly variable fuel consumption.

Table II. DESCRIPTION OF MODEL VALIDATION RUNS AND TESTING

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table II (continued). DESCRIPTION OF MODEL VALIDATION RUNS AND RESULTS

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 12. COMPARISON OF PASQUILL-TURNER (P-T) AND F. B. SMITH (F.B.S.) STABILITY ASSIGNMENTS FOR THREE DAYS OF HUNTINGTON, W. VA. 1973 SURFACE METEOROLOGICAL DATA[a]

Day No. 66		Day No. 134		Day No. 323	
P-T	F.B.S.	P-T	F.B.S.	P-T	F.B.S.
6	4.1	4	4.1	4	4.1
5	4.1	4	4.1	4	4.0
5	4.1	7	4.1	4	4.1
6	4.1	4	4.1	4	4.1
5	4.1	4	4.1	4	4.1
5	4.1	6	4.8	4	4.1
6	4.1	4	4.1	5	4.5
4	4.1	3	3.1	4	4.1
4	4.1	3	2.7	4	4.1
4	3.8	2	1.7	4	4.1
3	2.6	2	1.4	4	3.6
3	2.8	3	1.5	4	3.4
4	3.4	3	1.8	4	3.4
4	2.4	4	2.7	4	3.3
4	2.4	4	2.9	4	3.4
4	2.5	4	2.4	4	3.8
4	2.6	3	3.0	4	4.3
3	3.3	3	2.5	3	7.0
4	6.2	3	3.3	6	6.9
5	5.0	4	7.0	6	7.0
7	7.0	6	7.0	7	7.0
7	7.0	6	7.0	7	7.0
7	7.0	6	7.0	6	7.0
7	7.0	4	4.3	7	7.0

[a]A value of 0.4 has been added to the F.B. Smith stabilities so that they could be compared with the Pasquill-Turner values.

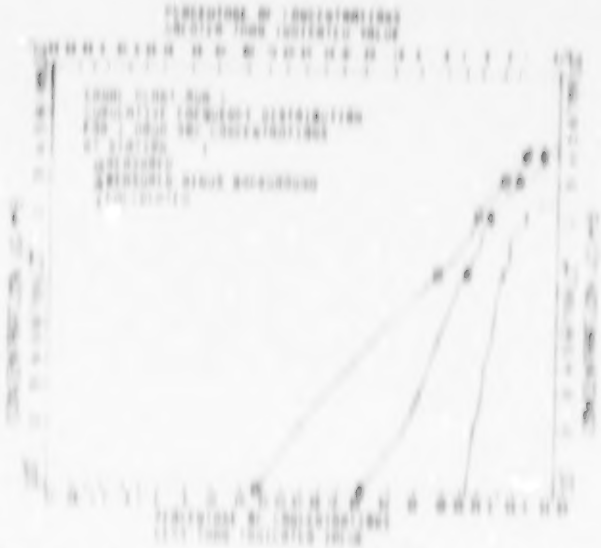

Figure 20a. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

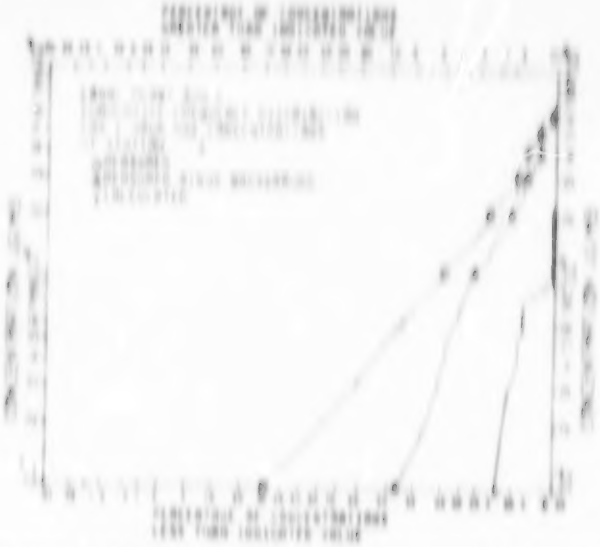

Figure 20b. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of hourly SO_2 concentrations for Canal Plant Station 2

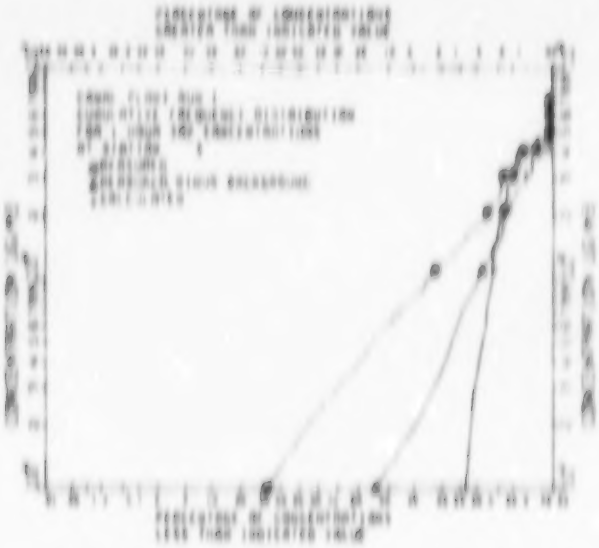

Figure 20c. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

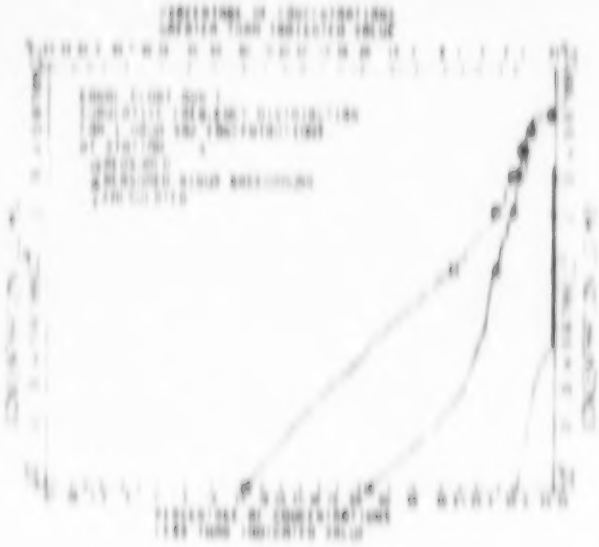

Figure 20d. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

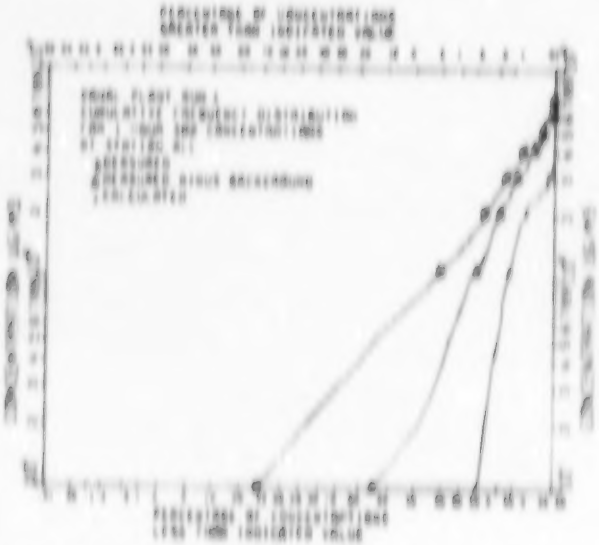

Figure 20a: Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

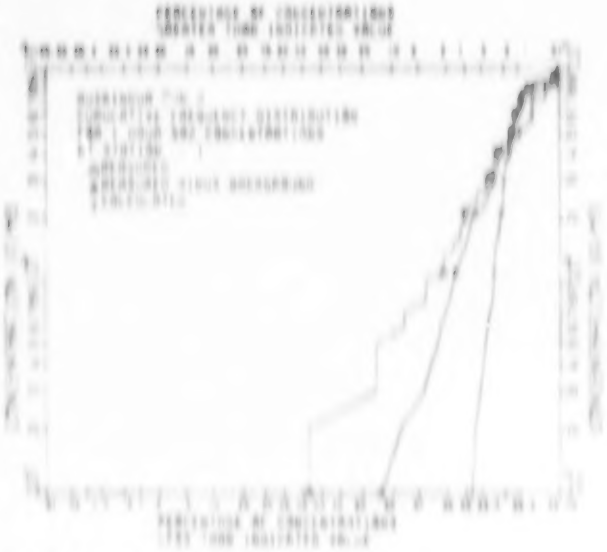

Figure 21a: Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

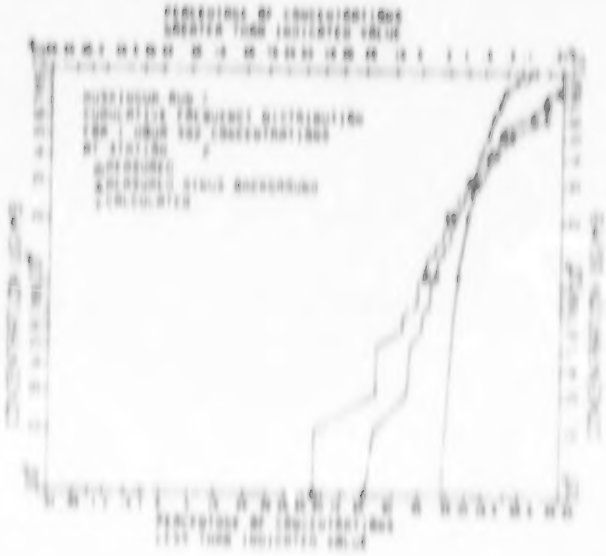

Figure 21b. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum River Station 3

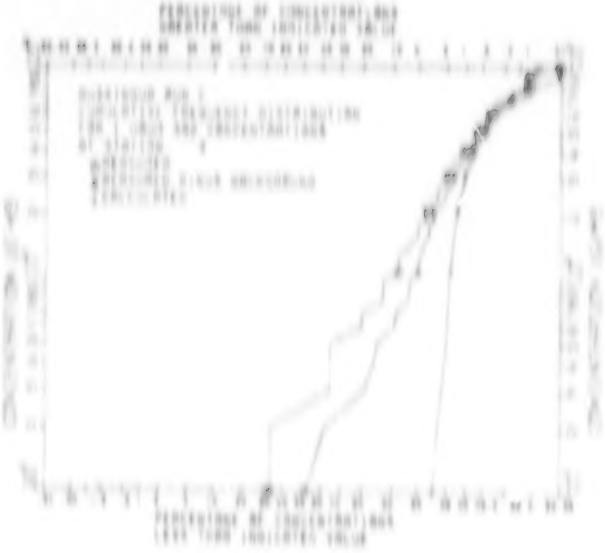

Figure 21c. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

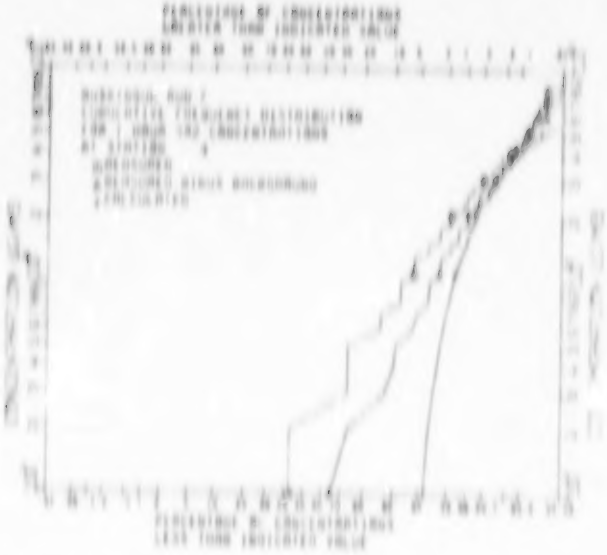

Figure 21d. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

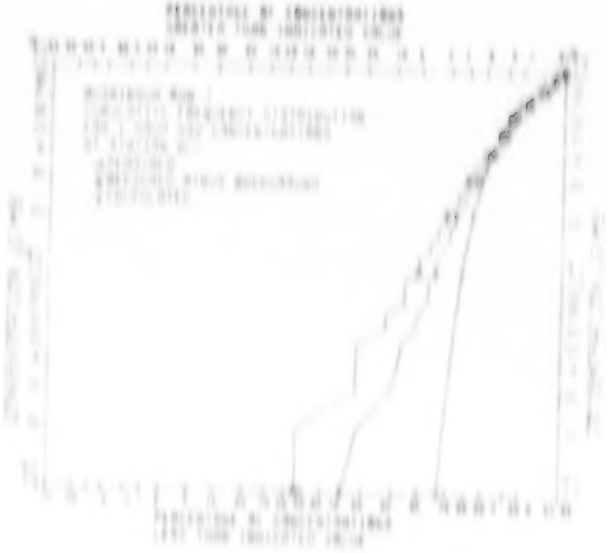

Figure 21e. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

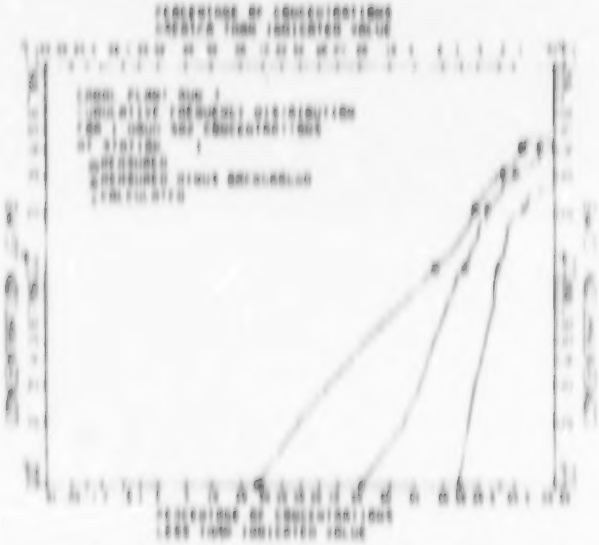

Figure 22a. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

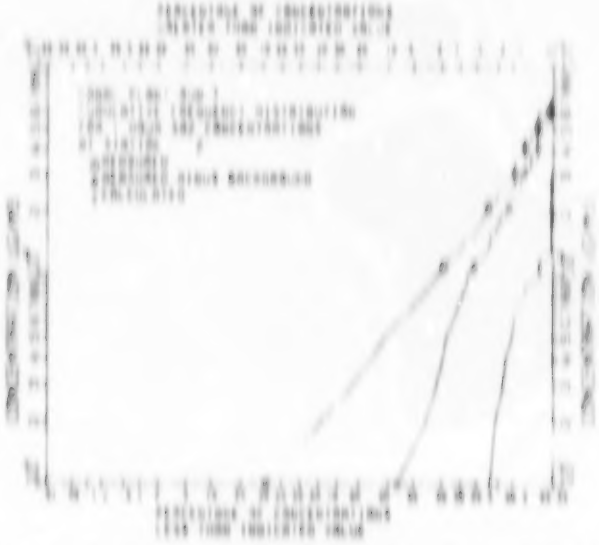

Figure 22b. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

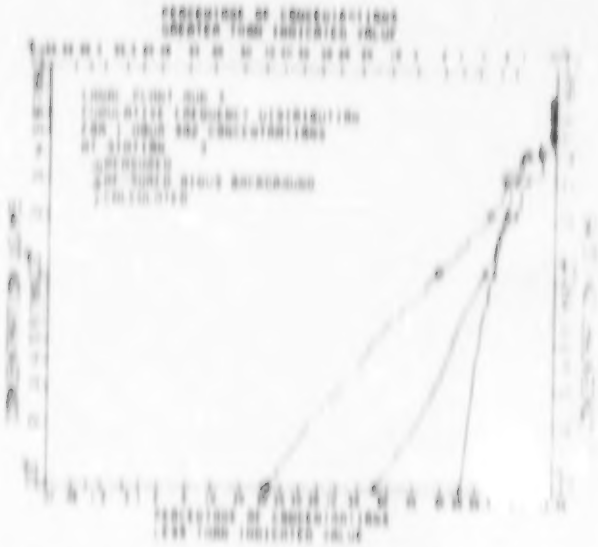

Figure 22c. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Beljaev dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

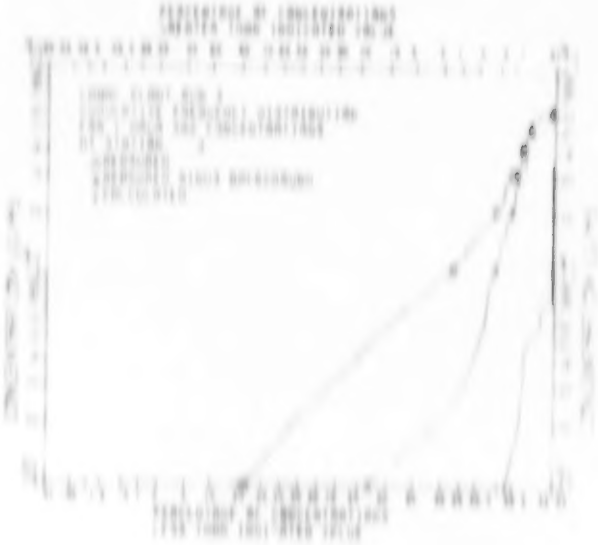

Figure 22d. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Beljaev dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 5

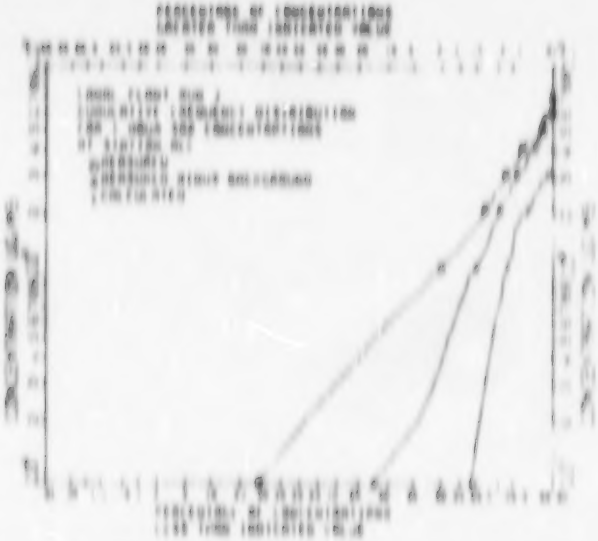

Figure 22a. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Beigas dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

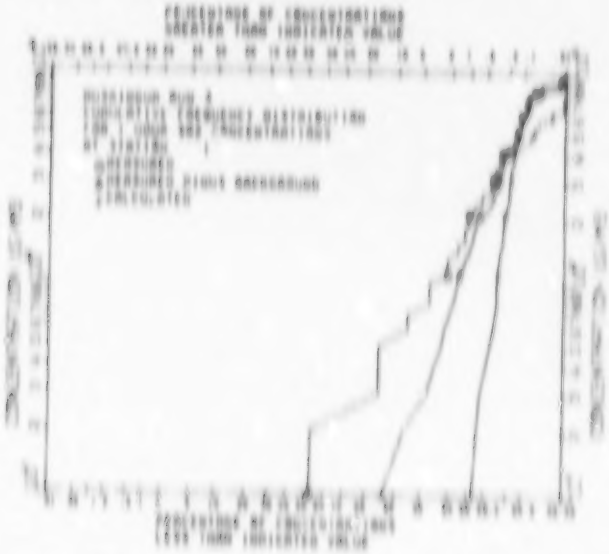

Figure 23a. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Beigas dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

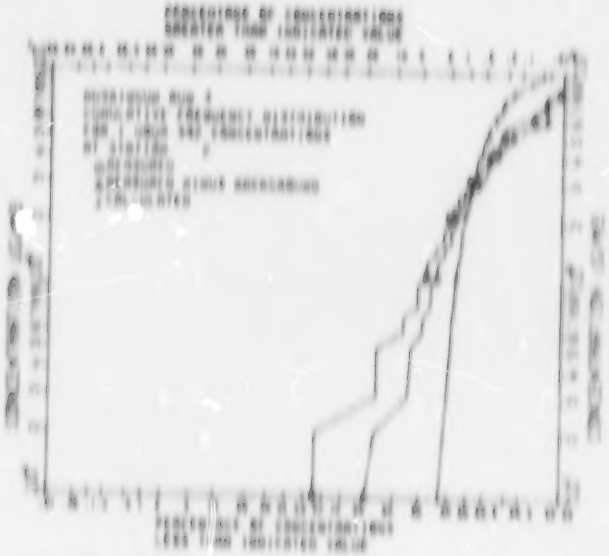

Figure 23b. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Hotzes dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

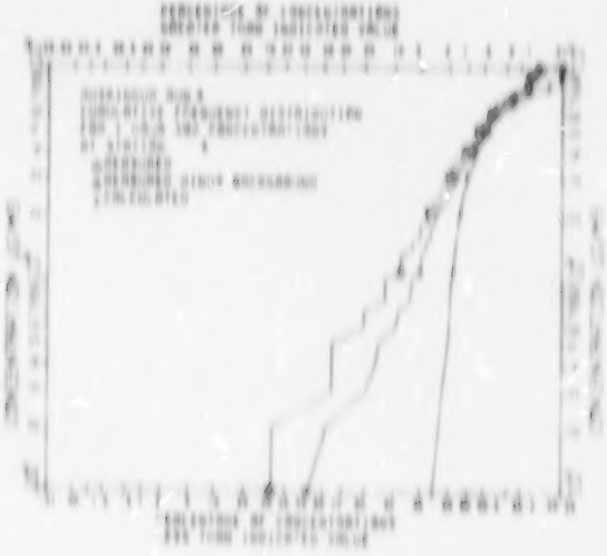

Figure 23c. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Hotzes dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

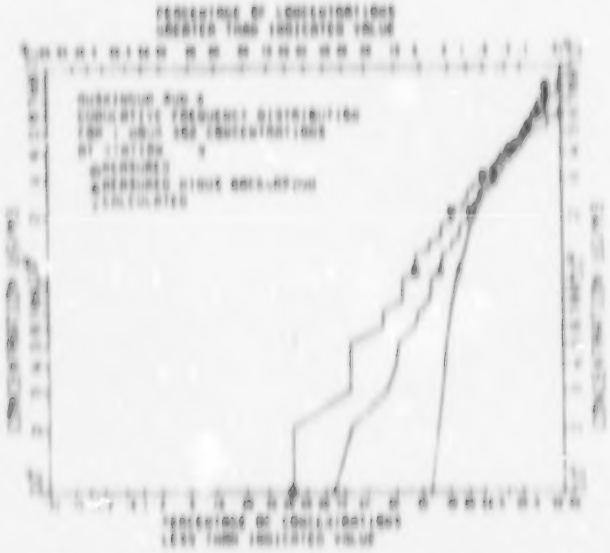

Figure 23d. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

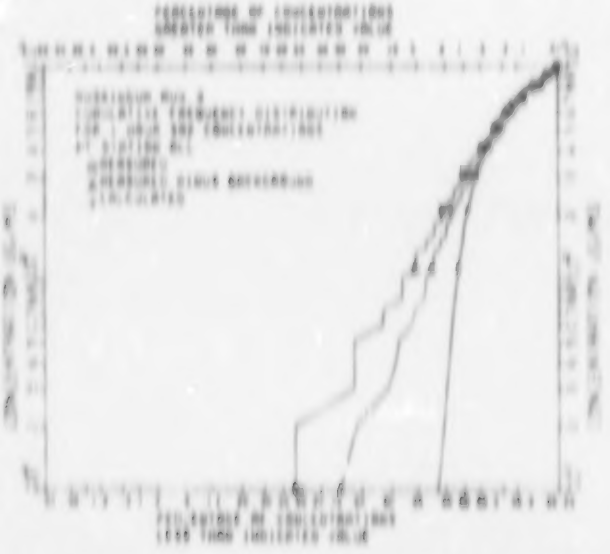

Figure 23e. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

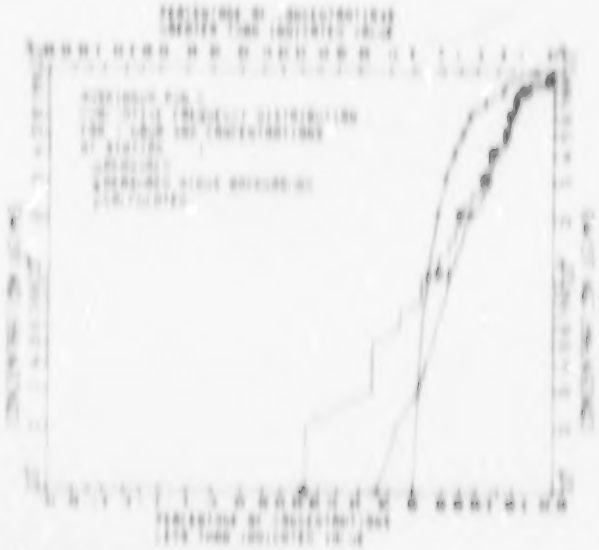

Figure 25a. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

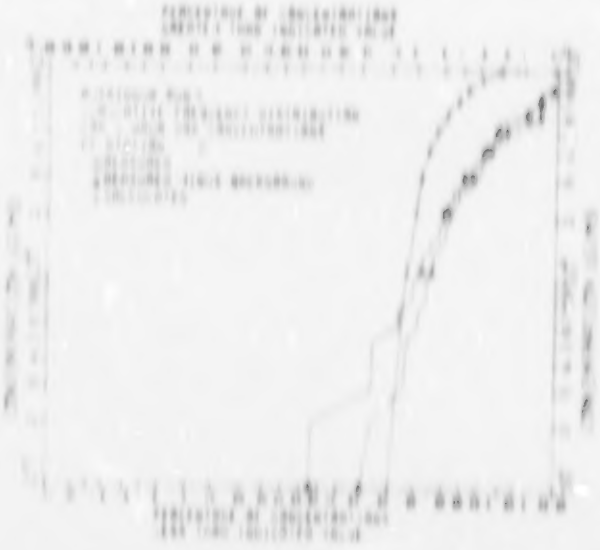

Figure 25b. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

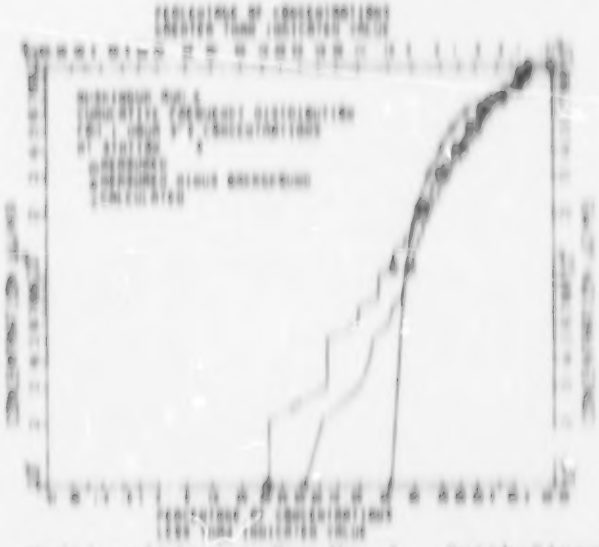

Figure 24c: Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

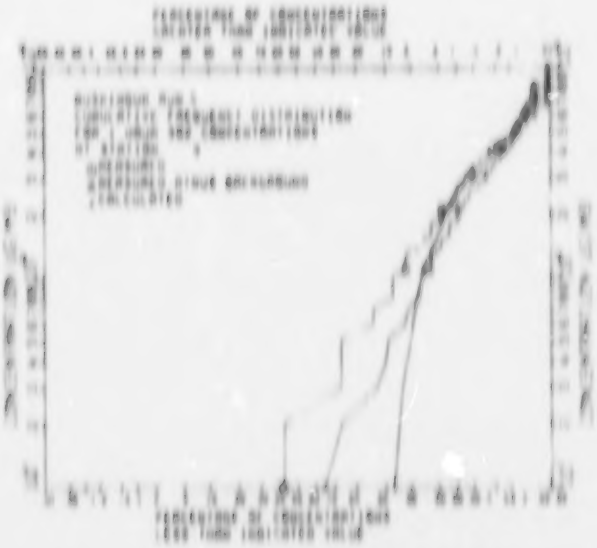

Figure 24d: Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

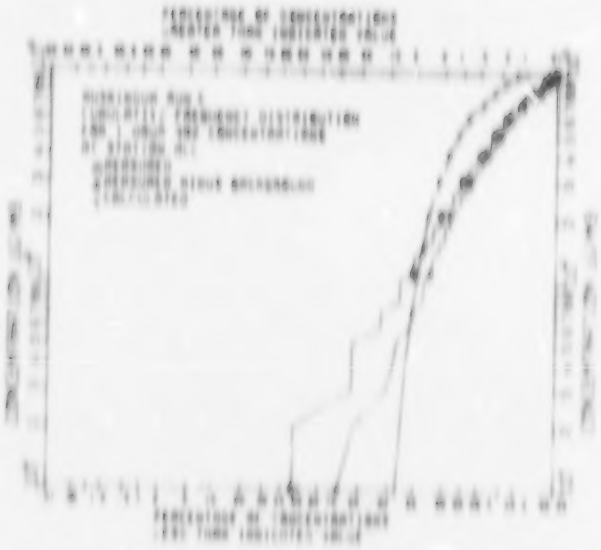

Figure 24a: Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

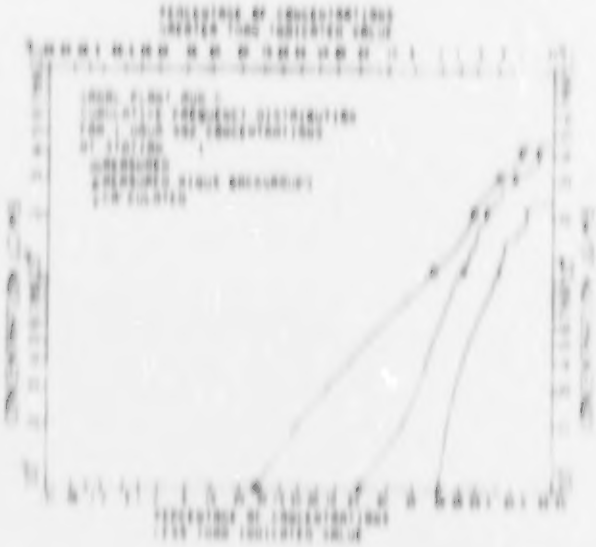

Figure 25a: Model validation Run No. 5. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

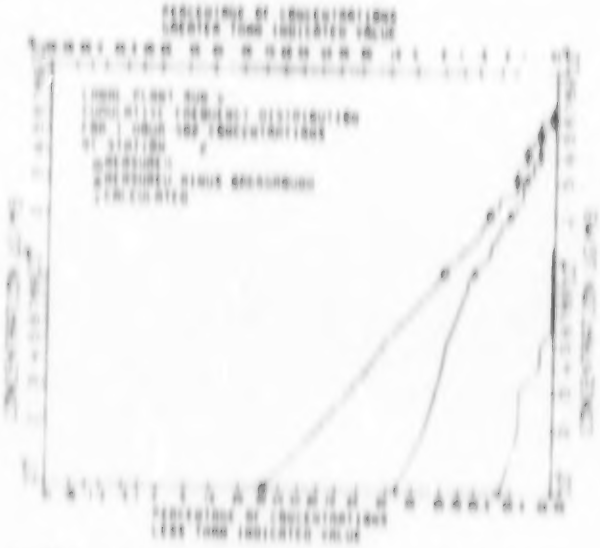

Figure 25b. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

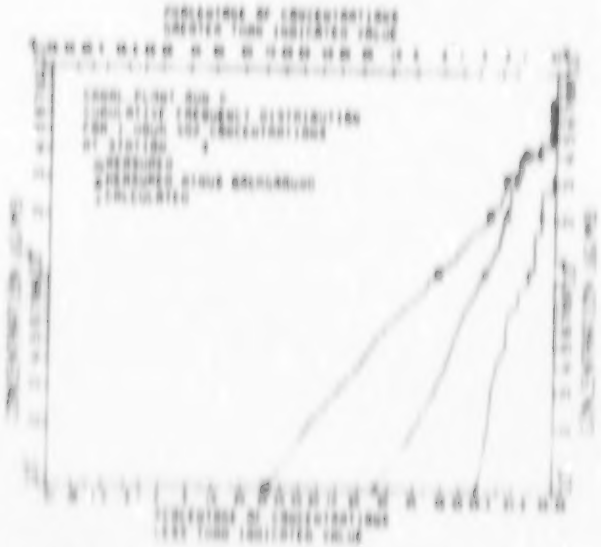

Figure 25c. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

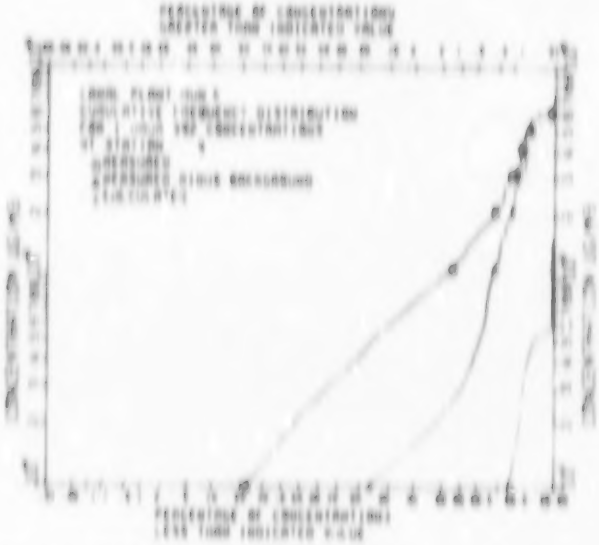

Figure 25d. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

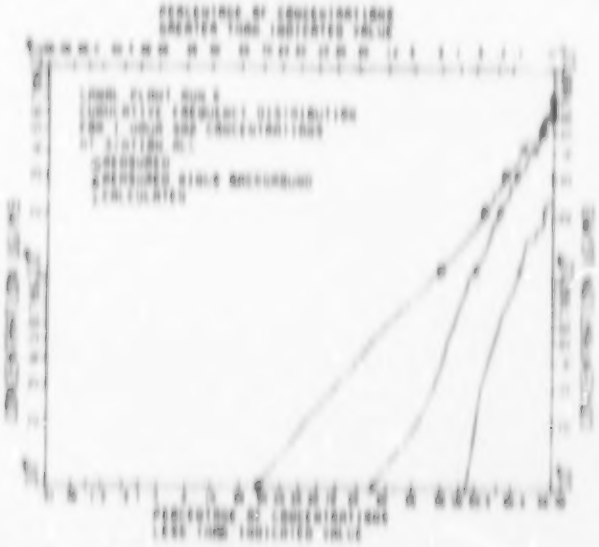

Figure 25e. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulativ, frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

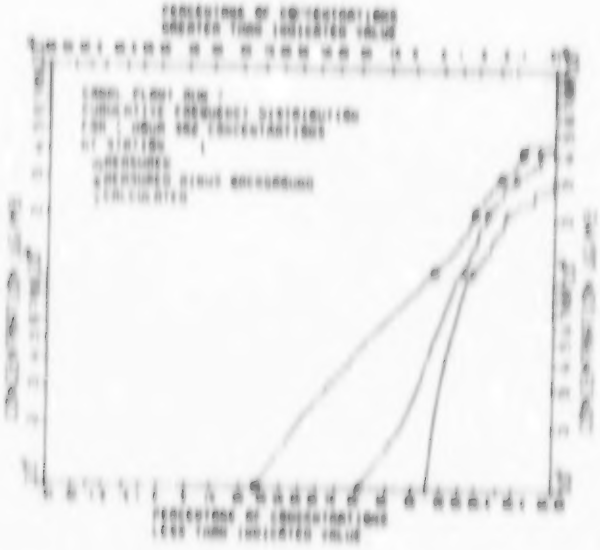

Figure 26a. Model validation Run No. 7. Pasquill-Turner stability assignment method and P.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

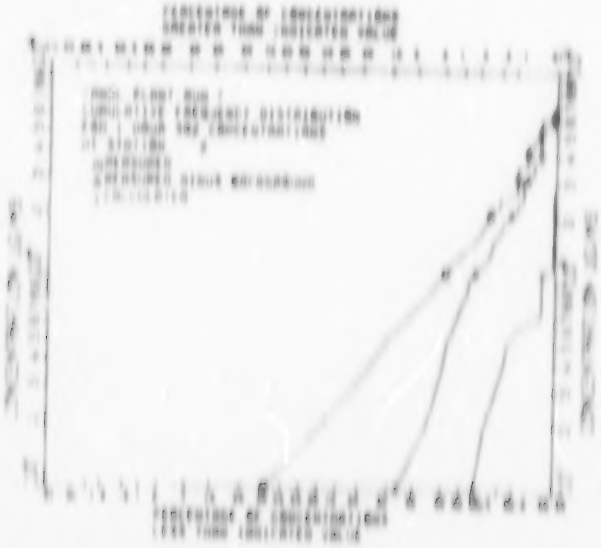

Figure 26b. Model validation Run No. 7. Pasquill-Turner stability assignment method and P.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

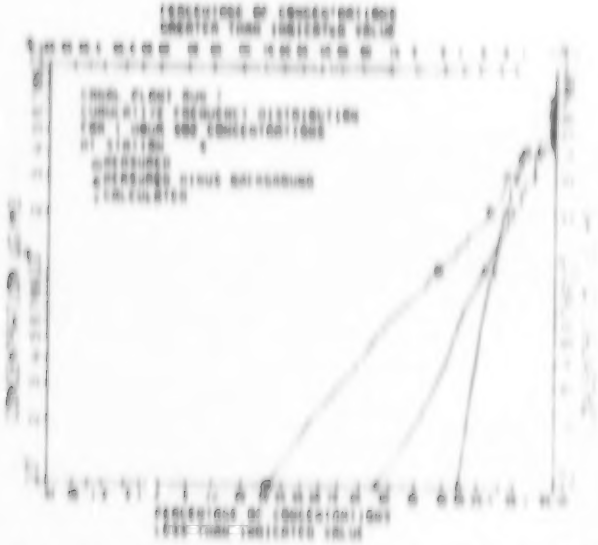

Figure 26c. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

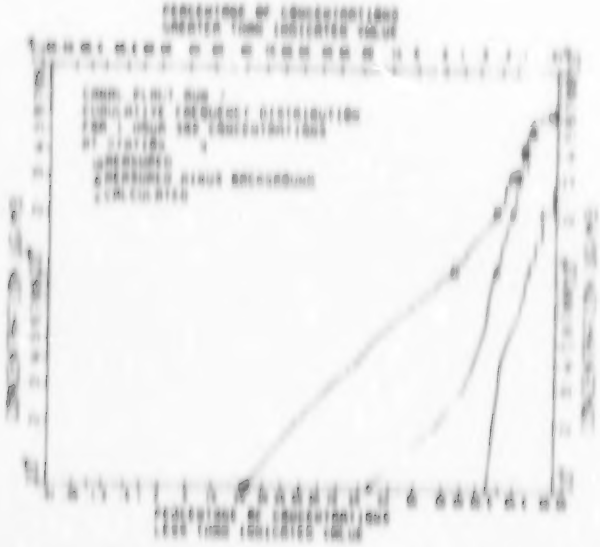

Figure 26d. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

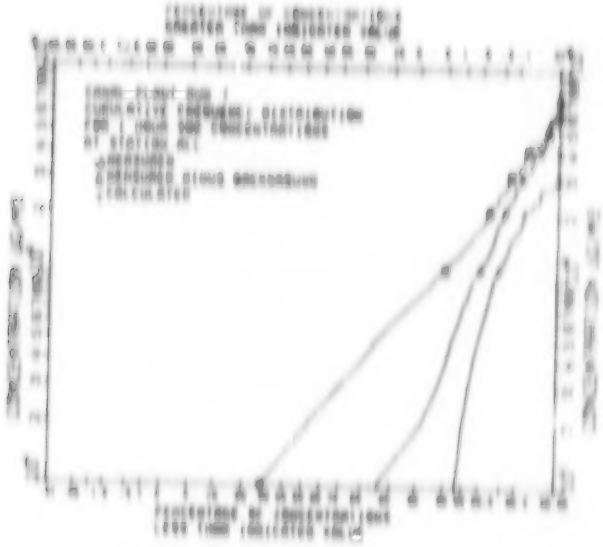

Figure 26a. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

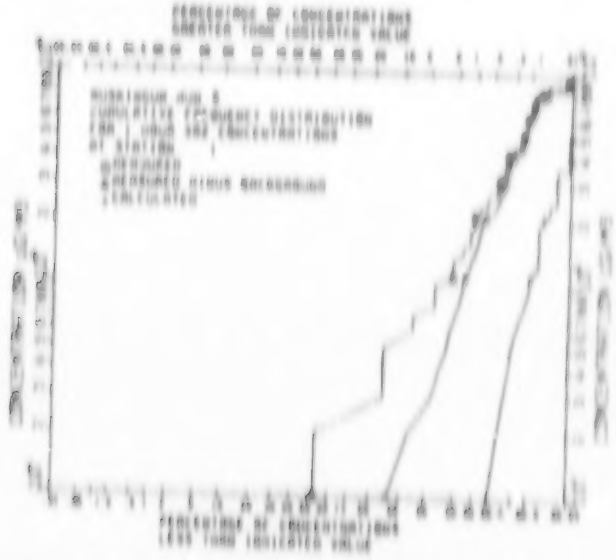

Figure 27a. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

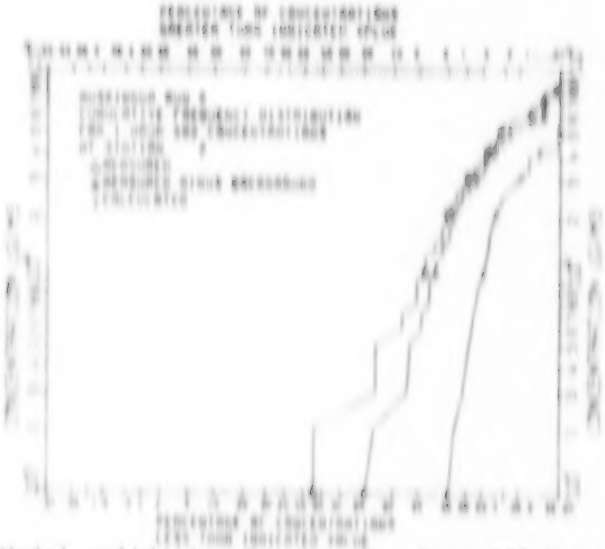

Figure 27b: Model validation Run No. 8. Pasquill-Turner stability assignment method and P.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

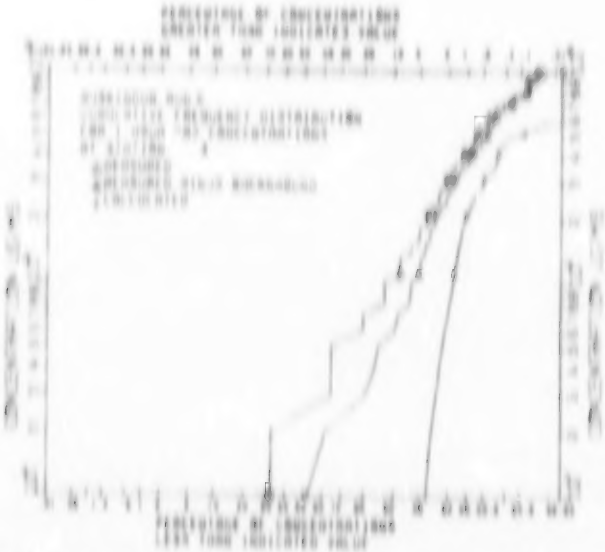

Figure 27c: Model validation Run No. 8. Pasquill-Turner stability assignment method and P.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

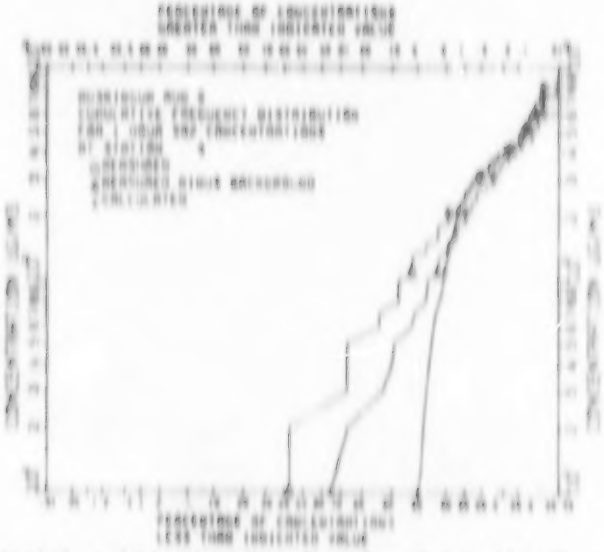

Figure 27d. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

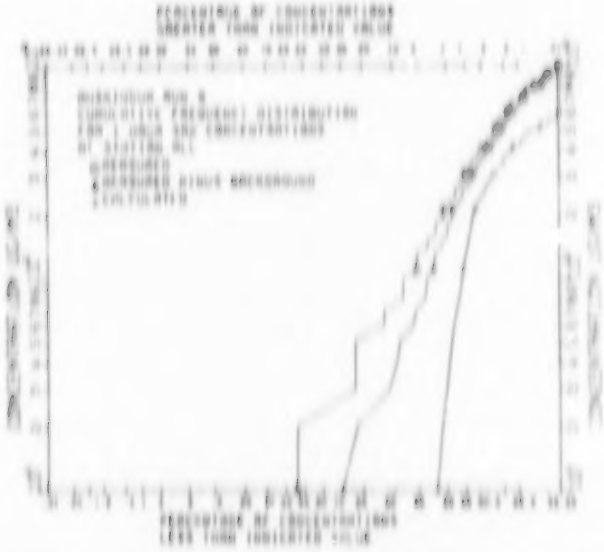

Figure 27e. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

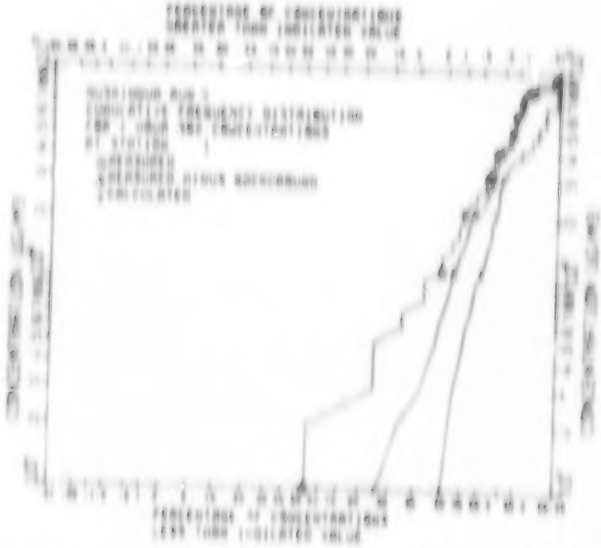

Figure 28a. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

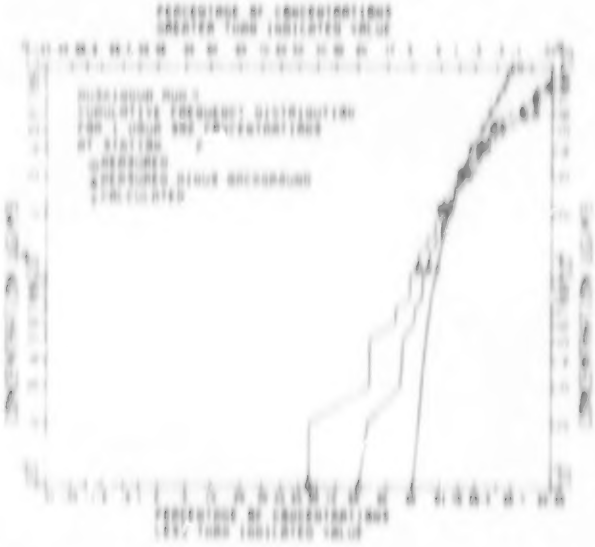

Figure 28b. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

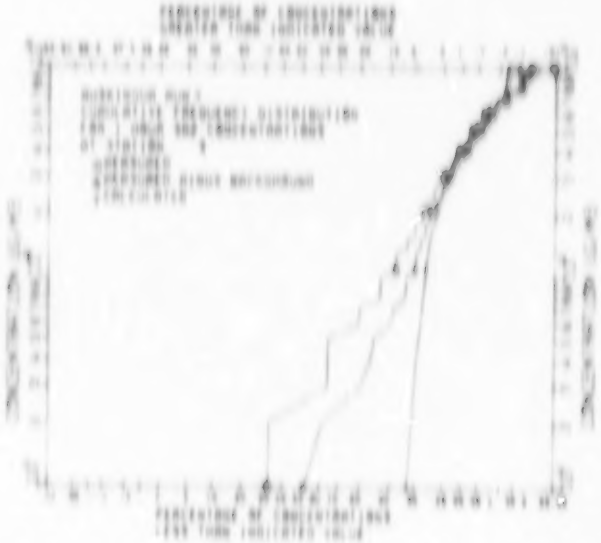

Figure 28c. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

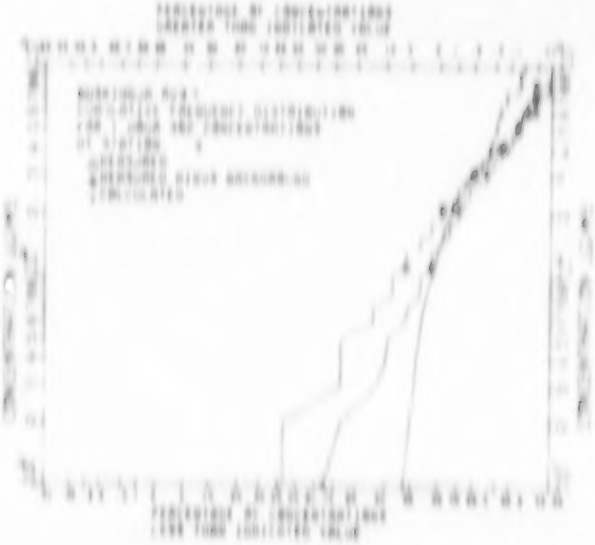

Figure 28d. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

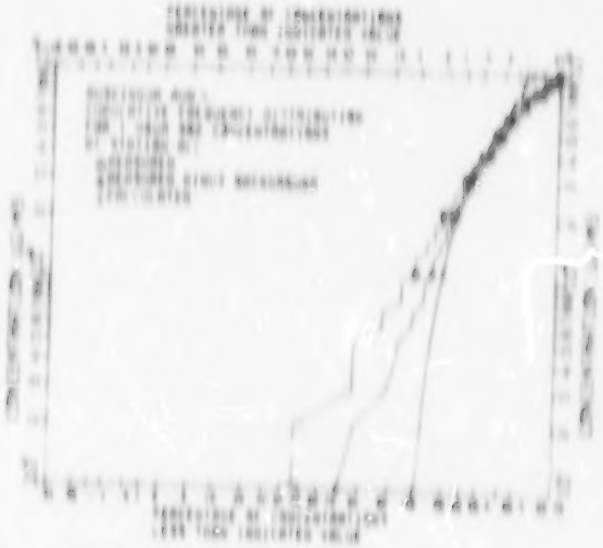

Figure 28a: Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations.

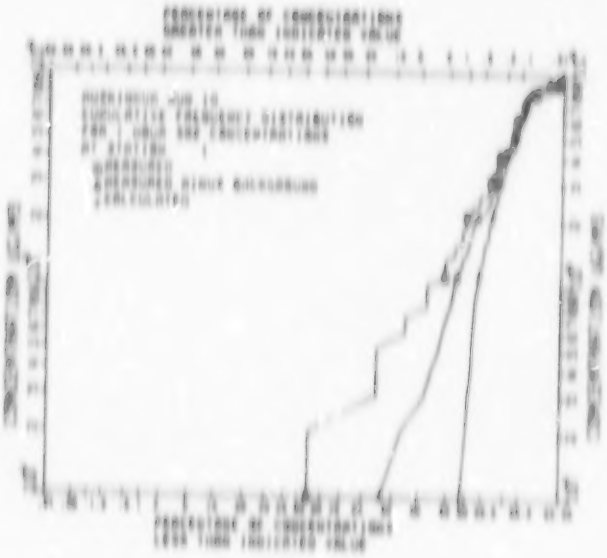

Figure 29a. Model validation Run No. 10. Variable buoyancy flux Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

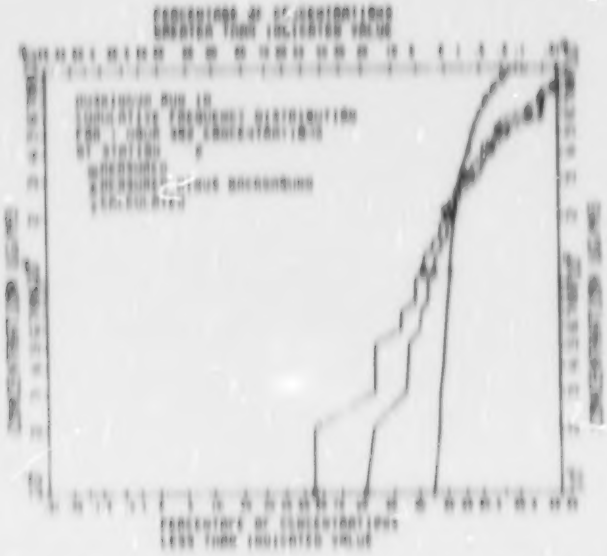

Figure 29b. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

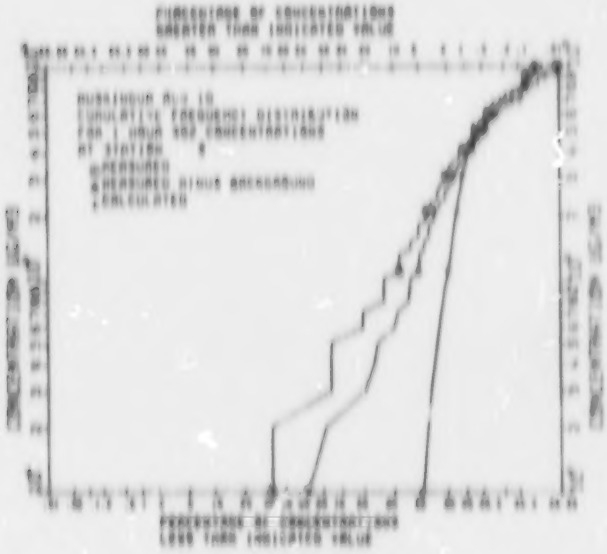

Figure 29c. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

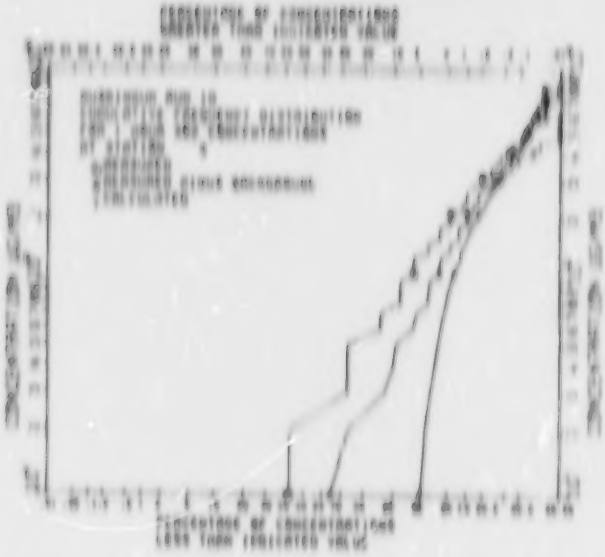

Figure 29d. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

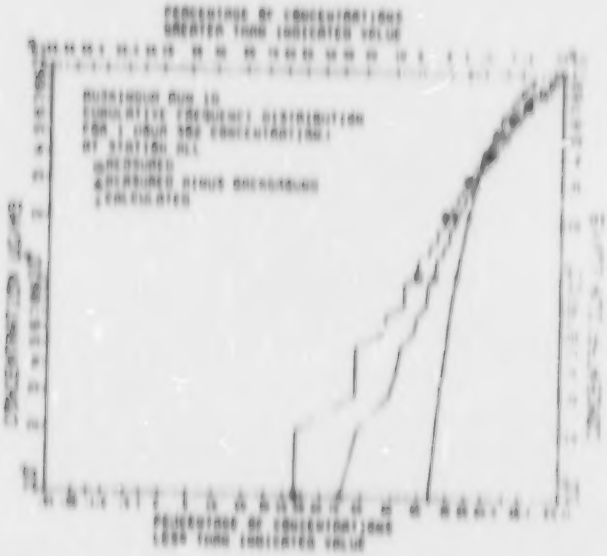

Figure 29e. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

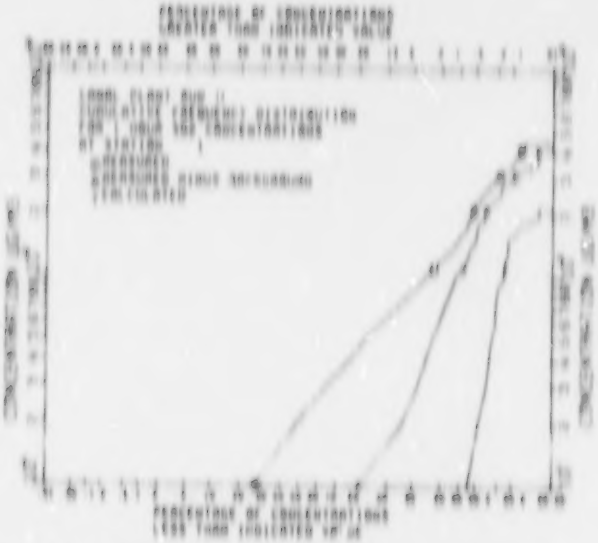

Figure 30a. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

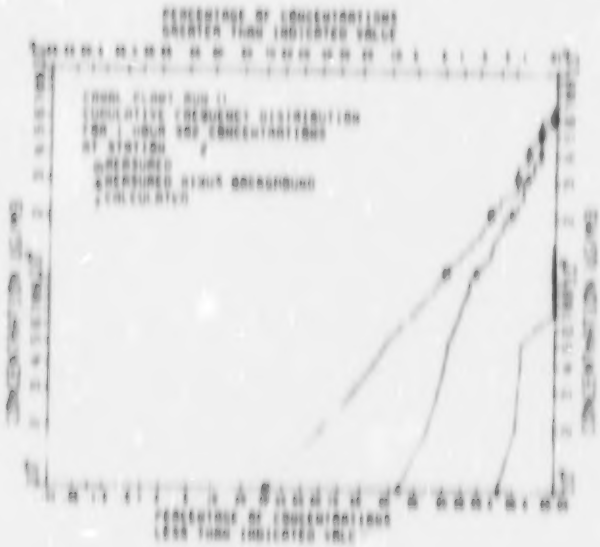

Figure 30b. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

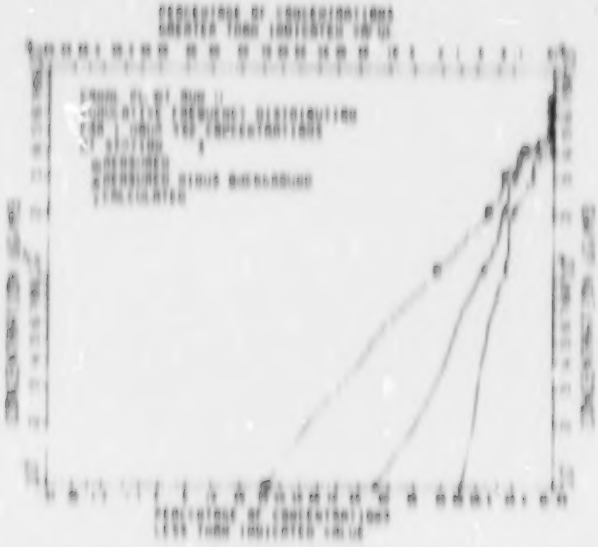

Figure 30c. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

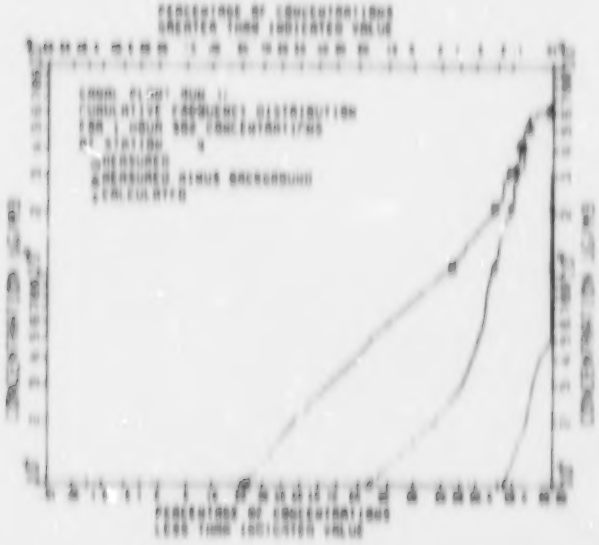

Figure 30d. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

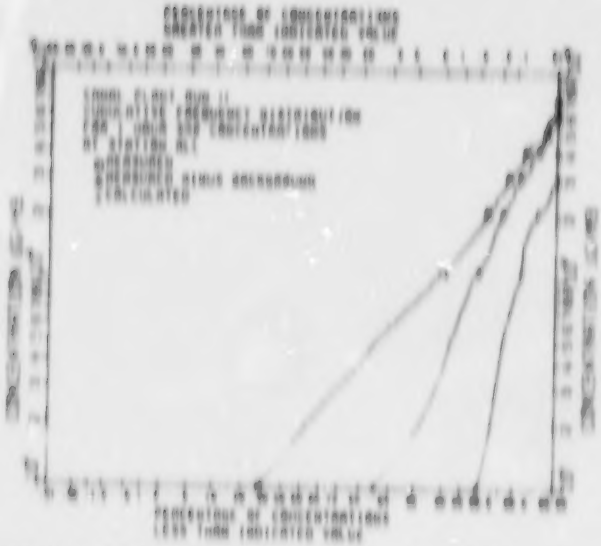

Figure 30a. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of this study we would recommend that the methods currently used for the calculation of dispersion coefficients and the selection of stability classes not be replaced by alternate techniques, at least until further model validation studies are conducted. Since data from only two power plants were used in this study the results could hardly be called definitive. Nevertheless, even from these limited results, we may draw a number of conclusions:

1. The similarity between the Pasquill-Turner and Gifford-Briggs dispersion coefficients (except for stability A) will require that a large number of model validation exercises be carried to determine which method is more accurate.

2. The use of the Smith-Singer stability assignment and dispersion calculation methods in the Single Source Model may yield unrealistic frequency distributions of 1-hour concentrations. This observation must be qualified, however, by the fact that the validation was carried out only for the Muskingum Plant. Since the rather subjective stability assignment scheme may have been carried out differently at the Muskingum Plant, the Smith-Singer version of the Single Source Model may give better agreement with measured concentrations if applied elsewhere.

3. Due to the strong variation of calculated concentrations as a function of stability, the use of fractional stability assignments should, in principle, lead to more accurate model predictions. The F.B. Smith stability classification method did not, however, provide better agreement between measured and calculated concentration frequency distributions, primarily because of its tendency to underestimate the stability class.

6. The use of a variable buoyancy flux in the Single Source Model did little to improve the agreement between measured and calculated concentration frequency distributions. This conclusion is similar to others reached when more detailed or applicable emissions or meteorological data has been used in model validation exercises. The success or failure of the model in any given application is much more a function of the assumptions regarding plume rise, dispersion, and terrain effects that form the theoretical basis for the model.

SECTION VI

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APPENDIX A

TURNER SCHEME FOR STABILITY CLASSIFICATION

The following scheme for stability classification was described by D. Bruce Turner in the February 1964 edition of the Journal of Applied Meteorology:

This system of classifying stability on an hourly basis for research in air pollution is based upon work accomplished by Dr. F. Pasquill of the British Meteorological Office. Stability near the ground is dependent primarily upon net radiation and wind speed. Without the influence of clouds, insolation (incoming radiation) during the day is dependent upon solar altitude, which is a function of time of day and time of year. When clouds exist their cover and thickness decrease incoming and outgoing radiation. In this system insolation is estimated by solar altitude and modified for existing conditions of total cloud cover and cloud ceiling height. At night estimates of outgoing radiation are made by considering cloud cover. This stability classification system has been made completely objective so that an electronic computer can be used to compute stability classes. The stability classes are as follows: (1) Extremely unstable; (2) unstable; (3) slightly unstable; (4) neutral; (5) slightly stable; (6) stable; (7) extremely stable. Table A-1 gives the stability class as a function of wind speed and net radiation. The net radiation index ranges from 4, highest positive net radiation (directed toward the ground), to -2, highest negative net radiation (directed away from the earth). Instability occurs with high positive net radiation and low wind speed, stability with high negative net radiation and light winds, and neutral conditions with cloudy skies or high wind speeds.

Table A-1. STABILITY CLASS AS A FUNCTION OF NET RADIATION AND WIND SPEED

Wind speed, knots	Net radiation index						
	4	3	2	1	0	-1	-2
0,1	1	1	2	3	4	6	7
2,3	1	2	2	3	4	6	7
4,5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8,9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
≥12	3	4	4	4	4	4	4

The net radiation index used with wind speed to obtain stability class is determined by the following procedure:

1. If the total cloud cover is 10/10 and the ceiling is less than 7000 feet, use net radiation index equal to 0 (whether day or night).

2. For night-time (between sunset and sunrise):

   a. If total cloud cover ≤4/10, use net radiation index equal to -2.

   b. If total cloud cover >4/10, use net radiation index equal to -1.

3. For daytime:

   a. Determine the insolation class number as a function of solar altitude from Table A-2.

   b. If total cloud cover ≤5/10, use the net radiation index in Table A-1 corresponding to the insolation class number.

   c. If cloud cover >5/10, modify the insolation class number by following these six steps.

      (1) Ceiling <7,000 ft, subtract 2.

Table A-2. INSOLATION AS A FUNCTION OF SOLAR ALTITUDE

Solar altitude (a)	Insolation	Insolation class number
$60^{\circ} < a$	Strong	4
$35^{\circ} < a \leq 60^{\circ}$	Moderate	3
$15^{\circ} < a \leq 35^{\circ}$	Slight	2
$a \leq 15^{\circ}$	Weak	1

(2) Ceiling $\geq$ 7000 ft but < 16,000 ft, subtract 1.

(3) Total cloud cover equal 10/10, subtract 1. (This will only apply to ceilings $\geq$ 7000 ft since cases with 10/10 coverage below 7000 ft are considered in item 1 above.)

(4) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.

(5) If modified insolation class number is less than 1, let it equal 1.

(6) Use the net radiation index in Table A-1 corresponding to the modified insolation class number.

The Pasquill-Turner technique for stability class assignment is the one currently employed in the Single Source Model Preprocessor program except that Table A-1 has been expanded to provide a greater resolution according to wind speed (see Table A-3).

Table A-3. ADAPTATION OF TABLE A-1 FOR USE IN THE SINGLE SOURCE MODEL PREPROCESSOR PROGRAM

Wind speed, knots	Net radiation index						
	4	3	2	1	0	-1	-2
1	1	1	2	3	4	7	7
2	1	2	2	3	4	7	7
3	1	2	2	3	4	6	7
4	1	2	3	4	4	5	7
5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8	2	3	3	4	4	4	5
9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
≥12	3	4	4	4	4	4	4

APPENDIX B

LISTINGS OF THE FRACTIONAL STABILITY PREPROCESSOR PROGRAM AND CORRESPONDING VERSION OF THE SINGLE SOURCE MODEL

PROP1: PROCEDURE OPTIONS(MAIN);

```
STMT LEVEL NEST
   1              PROP1: PROCEDURE OPTIONS(MAIN);
                  /* OCTOBER 1972 VERSION */
   2    1         DECLARE [illegible] FILE RECORD;
   3    1         DECLARE [illegible] FILE RECORD OUTPUT;
   4    1         DECLARE [illegible] FIXED DECIMAL(5,2),
                          [illegible]
                          [illegible] INITIAL [illegible]
                          [illegible] INITIAL [illegible]
                          [illegible] FIXED BINARY,
                          [illegible] INITIAL [illegible]
                          [illegible] FIXED DECIMAL [illegible]
                          [illegible] FIXED DECIMAL [illegible]
                          [illegible]
                          [illegible] INITIAL [illegible]
                          [illegible] FLOAT DECIMAL,
                          [illegible] FIXED DECIMAL [illegible]
   5    1         DECLARE [illegible] INITIAL [illegible]
   6    1         DECLARE [illegible] INITIAL [illegible]
                          [illegible]
                          [illegible] INITIAL
                          [illegible] INITIAL
                          [illegible] INITIAL
                          [illegible] FLOAT DECIMAL;
   7    1         DECLARE 1 INDATA,
                            2 ID PICTURE '99999',
                            2 IYEAR PICTURE '99',
                            2 IMONTH PICTURE '99',
                            2 IDAY PICTURE '99',
                            2 IHOUR PICTURE '99',
                            2 [illegible] CHAR(3),
                            2 [illegible] CHAR(2),
                            2 [illegible] PICTURE '99',
                            2 [illegible] PICTURE '99',
                            2 [illegible] CHAR(3),
                            2 [illegible] PICTURE '999',
                            2 [illegible] CHAR(2),
                            2 [illegible] CHAR(1),
                            2 [illegible] CHAR(1),
                          1 OUTDATA,
                            2 YR PICTURE '99',
                            2 MONTH PICTURE '99',
                            2 DAY PICTURE '999',
```

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```
PROG:   PROCEDURE OPTIONS(MAIN);

START LEVEL MOST
                        /* DECLARE: PICTURE '999';
                        /* DECLARE: PICTURE '999999';
                        /* DECLARE: PICTURE '999999';
                        /* DECLARE: PICTURE '999';
                        /* DECLARE: PICTURE '999';
                        /* DECLARE: PICTURE '999999999';
 8      |       DECLARE TEMP(5) CHARACTER;
 9      |       DECLARE TEMP(5) CHARACTER;
10      |       FT1:      FORMAT(COL(15),F(4,0),COL(25),F(4,0));
11      |                 ON ENDFILE(SYSIN) GO TO EXIT;
                /* READ CARD TO INITIALIZE DET TAPE TO READ A LAST RECORD CORRECTLY */
12      |       ALOOP:    GET FILE(SYSIN) DATA (IDF,IMO,ICHD,ALAT,ALONG,ZONE,TITLE);
                                TITLE(1);
13      |                 IDES(1) = IMO(1) || IMO(2);
14      |                 DATE(1) = IDF(1) || IDF(2);
15      |                 DATE(2) = IDF(3) || IDF(4);
16      |                 ON ERROR GOTO ERROR1;
                          /* ERROR NOT FILE(SYSPRINT) ONCE
                          PUT SKIP(2) A AT TIME OF ERROR CONDITION=',ERROR( (A(50),F(5,0)));
                          ON ENDFILE(SYSIN) GO TO EXIT;
21      |       /* READ A CARD WITH CITY COORD DATA */
22      |                 READ FILE(SYSIN) INDUTMOATE;
23      |       /* READ PRIOR DAYS MEAN OUTGOT VALUES */
24      |                 GET FILE(SYSIN) COUT   (TEMP(I),I=1,4) (I(1),I);
25      |       /* READ PRESENT DAYS MISSING INCOMT VALUES */
25      |                 GET FILE(SYSIN) COUT   (TEMP,I=1,4) (I(1));
26      |       /* ENTER DAY LOOP TO READ NEXT DAYS MISSING INCOMT VALUES */
29      |                 DO I=1 TO 365;
30      |  1              GET FILE(SYSIN) COUT   (TEMP(I),I=1,5) (I(1));
31      |  1      /* CALC LATE THE DATEN AND THE TIME OF SUNRISE AND SUNSET */
32      |  1              CALL SOLTIME(ZONE, IMONTH);
33      |  1      /* CONSTANT ZONE,ALAT,ALONG,ZONE,TIME  */
34      |  1              CALL DATE(I,DATEN,IYEAR,IMONTH,IDAY);
35      |  1                 TIMEZONE=ZONE;
36      |  1                 SINDEC=SINDEC(I);
37      |  1                 COSDEC=COSDEC(I);
38      |  1                 SINTDC=SINTDC(I);
39      |  1                 COSTDC=COSTDC(I);
40      |  1                 SIGMA=ATN (SINDEC/(COSDEC*SINTDC));/*SIGMA=DECLINATION*/
41      |  1                 D=DEGREES(SIGMA);/*D=DECLINATION*/
42      |       /* CONSTANT  A,DELTAGMT,D,SINDEC,COSDEC,TIMEZONE  */
43      |  1                 DELTAGMT=ABS(ALONG/15-TIMEZONE);
44      |  1                 DECDEGREE=D;/*DECDEGREE=D*/
45      |  1                 ANG=ATN(-TAN(ALAT)*TAN(D));/*ANG=HOUR ANGLE OF SUNRISE*/
46      |  1                 SINLAT=SIN(ALAT/CONST);
47      |  1                 COSLAT=COS(ALAT/CONST);
48      |  1                 HOURSUNRISE=DEGREES(ACOS(-TAN(ALAT)*TAN(D)));
49      |  1                 HOURSUNSET=-HOURSUNRISE;/*HOURSUNSET=-HOURSUNRISE*/
50      |  1                 TSR=(ALONG/15-DELTAGMT-ANG/15)/CONST;
51      |  1                 TSS=(ALONG/15-DELTAGMT+ANG/15)/CONST;
52      |  1                 DO K=0 TO 23;
53      |       /*CHECK DATA FOR CORRECTNESS & CONTINUITY */
54      |  1    CHECK1:   IF IDF=IDF THEN DO;
                            PUT SKIP FILE(SYSPRINT) ONCE
                            ('IDF DOES NOT MATCH TO RECORD # ',ERROR(1),'  DD IS ',IDF
                            (R(10),F(2,0),X(1),F(2,0),X(1),A(1))
```

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```
USER:  PROCEDURE OPTIMIZE(MAIN);

START LEVEL ONEST

 07     |     |              GO TO NEWREC;
 08     |     |              END;
 09     |     |          IF TYEAR =[illegible] THEN DO; PUT SKIP FILE(SYSPRINT) EDIT
                            ('YEAR [illegible] DOES NOT AGREE WITH LOWER [illegible] INDEX:',INDEX,
                            [illegible]);
 10     |     |              GO TO NEWREC; END;
 11     |     |          OUTDATA.YRCTYEAR=
 12     |     |          IF [illegible]=[illegible] THEN      IF [illegible]=[illegible]  THEN DO;
                            PUT SKIP FILE(SYSPRINT) EDIT
                            ('MONTH [illegible] DOES NOT AGREE WITH LOWER [illegible]' INDEX);
                            [illegible]
 13     |     |              GO TO FINISH; END;
 14     |     |          OUTDATA.MONTH=[illegible]
 15     |     |          IF [illegible]=[illegible] THEN DO; PUT SKIP FILE(SYSPRINT) EDIT
                            ('DAY [illegible] DOES NOT AGREE WITH LOWER [illegible]' INDEX);
                            [illegible]
 16     |     |              GO TO NEWREC; END;
 17     |     |          IF [illegible]=[illegible] THEN DO; PUT SKIP FILE(SYSPRINT) EDIT
                            ('HOUR [illegible] DOES NOT AGREE WITH LOWER [illegible]' INDEX);
                            [illegible]
 18     |     |          [illegible]
                        END;
                /* CONVERSION OF [illegible] TO [illegible]  */
 19     |     |          IF [illegible]='[illegible]' THEN [illegible]=[illegible];
 20     |     |           ELSE [illegible]=[illegible];
 21     |     |           IF [illegible]='[illegible]' THEN [illegible]=[illegible];
 22     |     |           ELSE [illegible]=[illegible];
                /* [illegible] AT TEMPERATURE [illegible] TO KELVIN  */
 23     |     |          OUTDATA.[illegible]=[illegible]+[illegible];
                /* CONVERT WIND SPEED FROM KNOTS TO METERS/SECOND  */
 24     |     |          [illegible]=[illegible]*[illegible];
 25     |     |          IF [illegible] THEN [illegible];
 26     |     |          OUTDATA.SPEED=[illegible];
                [illegible];
                /* CHECK FOR CALMS */
 27     |     |          IF [illegible]=[illegible] THEN [illegible]=[illegible];
 28     |     |           ELSE [illegible]=[illegible];
                [illegible];
                /* CALCULATE FLOW VECTOR AND RANDOM FLOW VECTOR  */
 29     |     |          IF [illegible]=[illegible] THEN [illegible]=[illegible];
 30     |     |           ELSE [illegible];
 31     |     |          OUTDATA.[illegible]=[illegible];
 32     |     |          [illegible]
 33     |     |          [illegible]
 34     |     |          IF [illegible] THEN [illegible];
 35     |     |          [illegible]
100     |     |          [illegible]=[illegible]-[illegible] ;
101     |     |          [illegible] ;
102     |     |          END;
103     |     |          [illegible];
104     |     |          OUTDATA.[illegible]=[illegible]-[illegible]  ;
105     |     |          IF [illegible] THEN
106     |     |           OUTDATA.[illegible]=OUTDATA.[illegible];
                /* [illegible] */
```

```
      PROC:  PROCEDURE OPTIONS(MAIN);

START LEVEL ONEST

                    IF SIN, THEN GO TO OR;
                    IF INDWATTS THEN GO TO S1;
                    IF INDWATTS THEN GO TO S1;
            /* DETERMINE THE ANGLE OF ELEVATION  */
            DECLARE( DTT,DTT,DDT,DDMT,DMMT,ALMDT,ZCMDT;
               ALFA=SOLAR(DDT,DMMT,ALMDT,ZCMDT);
                    ALF=ATAND(SIN,SQRT(1-ALFA**2));
                    ZALF=90-ALF;
                    ADD=DTT-DDMT/REALF;
                    ZALF=ZALF/CONST;
                    DECLARE(ZTRANF(11),CONSTANT(11));
            /* INTERPOLATE THE INCOMING SOLAR RADIATION FACTOR */
                    DO I=2 TO 9;
                    IF ZALF>=ZTRANF(I) & ZALF<=ZTRANF(I+1) THEN GO TO A1;
                    END;
            A1      DECLARE
                    (MULT,CONSTANT(I-1)+(ZCTRANF(I)-ZALF)*(CONSTANT(I)-CONSTANT(I-1))
                    /(ZTRANF(I)-ZALF));
                    WATTS=WATTS*MULT;
                    IF WATTS>0, THEN GO TO S1
            /* FIND STABILITY USING RADIATION, WIND, AND CLOUD COVER */
                    DO I=2 TO 7;
                    IF WINDMIN(I) & WINDMIN(I+1) THEN GO TO B1;
                    END;
            B1      DECLARE
                    (SCUFF(I),M1 SCUFF(I+2),MINWATTS(SCUFF(I),MINWATTS(SCUFF(I+1),M1
                    WATTS>=0);
                    CALCUL (A1)(SCUFF(I+2),AIRWATTS(SCUFF(I),AIRWATTS(SCUFF(I+1),A1
                    WATTS>=0);
                    DECLARE(WIND(I)) (WINDMIN(I)- 5  (WIND-(5)/(WINDMIN(I)-WINDMIN(I)))
                    DO I=1 TO 3;
            DD:     DECLARE(A1
                    DO I=1 TO 3;
            /* CALCULATE STABILITY USING CLOUD COVER AND WINDSPEED */
            C1      DO I=2 TO 5;
                    IF WINDMIN(I) & WINDMIN(I+1) THEN GO TO CC;
                    END;
            CC:     DECLARE
                    WINDIFF;
                    DECLARE
                    (M1,SCUFF(I),M1SCUFF(I),M1SCUFF(I+1),M1SCUFF(I+2),M1SCUFF(I+3),M1
                    M2,SCUFF(I),M2SCUFF(I),M2SCUFF(I+1),M2SCUFF(I+2),M2SCUFF(I+3),M2
                    CLOUDS);
                    DECLARE(WIND(I)) (WINDMIN(I)- 5  (WIND-(5)/(WINDMIN(I)-WINDMIN(I)))
            D1      DECLARE(CONSTANT(10),A1
                    DECLARE(TEST(10),RESTRICTED(10),A1
                    OUTDATA,RESTRICTED=0;
                    IF TEST(I) THEN OUTDATA,RESTRICTED=TO;
            /* CALCULATE MIXING HEIGHT */
                    DHM=SUCCF;
                    DHM=THM;
                    IF SUMCFA THEN IF HUMA<=TSS THEN DO;
                      HUMT(I)=HUMT(I)*F;
                      HUMT(I)=HUMT(I)*F;
                      GO TO 'DEGFIT' TWO;
```

```
PROC: PROCEDURE OPTIONS(MAIN);

CTRF LEVEL MOST

                    END;/*
                    IF SUM<=TSS THEN DO;
                      IF ELEVRONT=0 THEN DO;
                        HLHIT,SUMT=SAF;SRMHT=SAF;R1=SUM-TSS;/100,-TSS;/*
                        END;/* END;
                      HLHIT,SUMT=SAF;SRMHT=SAF;R1=SUM-TSS;/100,-TSS;/*
                      IF SUM>0 THEN HLHIT,SUMT=HLHIT,SUMT;/*
                    GO TO NEXRECL; END;
                    IF SUM>=TSS THEN DO;
                      SAFSR=SAFSRMHT;
                      IF ELEVRONT=0 THEN DO;
                        HLHIT,SUMT=SRMHT;
                        END;/* END;
                      HLHIT,SUMT=SRMHT;R1=SAF-SAFSR;/100,-TSS;SUMT;/100,-TSS;/*
                      IF SUM>0 THEN HLHIT,SUMT=HLHIT,SUMT;/*
                    GO TO NEXRECL; END;
                    IF ELEVRONT=0 THEN DO;
                      HLHIT,SUMT=SRMHT;SAF=SRMHT;R1=SUM-TSS;/100,-TSS;/*
                      HLHIT,SUMT=SAF;R1=SUM-TSS;/100,-TSS;/*
                      END;
                    ELSE DO;
                      HLHIT,SUMT=SAFSR;SAF=SAFSR;R1=SUM-TSS;/100,-TSS;/*
                    HLHIT,SUMT=HLHIT,SUMT;
                      END;
                /* READ NEXT HUMAN'S RET DATA */
                NEXRECL: IF EOF=0 THEN DO;
                        READ FILE(RETDATA) INTO(INDATA);
                        LOC=' 0010';
                        END;
                        ELSE GOTO
                HLINIC: END;
                /* UPDATE MISSING HEIGHTS */
                        SMOM=SMOM;
                        SAFMS=SAF;
                        SRM=SMOM;
                        SAF=SAFMS;
                /* WRITE A DATA CALCULATIONS ON TO TAPE */
                        WRITE FILE(MRT) FROM(OUTDATA);
                HLOUT: END;
                LAST:   WRITE FILE(MRT) FROM(OUTDATA);
                        CLOSE FILE(RETDATA),FILE(MRT);
                        DIV 'SKIP FILE(RESPONSE); RUN;
                        /* ALL RECORDS HAVE BEEN PROCESSED */ /*/*/*
                        GO TO AGAIN;/*
                FINISH: END PROC;
```

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```
FORTRAN IV G1  RELEASE 2.0          MAIN            DATE = 76154          12/29/01

0000          DATA COMBATIVE,TEVH,T,EZ,FF                                   00000001
              CHARACTER*1 ANSWER                                            00000002
0000               ZERO=0.0                                                 00000003
0003               ZERO=0                                                   00000004
0006               ZERO=0                                                   00000005
0007               DO 1 I=1,NMAXN                                           00000006
0008               CHARGE(I)=0.0                                            00000007
0009               DO 2 I=1,N                                               00000008
0010          1    CHARGE(I)=0.0                                            00000009
0013               DO 3 I=1,N                                               00000010
0014          2    CHA(I)=0.0                                               00000011
0015          3    CONTINUE                                                 00000012
              C***                                                          00000013
              C***INPUT DECAYED RANGES                                      00000014
0016               READ(5,NMAX,END=                                         00000015
0018               WRITE(6,NMAX,)                                           00000016
              C***CALCULATE AND STORE DECAYED FOR A CASE A DATA SET.        00000017
              C***INTERVAL IS ASSUMED TO BE 15 SECONDS                      00000018
              C***                                                          00000019
0019               DO 7 I=1,NDATA                                           00000020
0020               READ(5,                                                  00000021
0021               DO 7 K=1,NDECAY                                          00000022
0023               CALL SIGMA(K,X,KSTR,SK,SZ)                               00000023
0025               SYGM(K)=SK/SZ                                            00000024
0027               SZGM(K)=SZ/SZ                                            00000025
0029          7    CONTINUE                                                 00000026
              C***                                                          00000027
              C***INPUT SOURCES TO BE CONSIDERED                            00000028
0031          8    READ(5,                                                  00000029
0033               CALL(5,END=                                              00000030
0037               IF(ANSWER.EQ.'Y') GO TO 9                                00000031
0038               IF(ANSWER.EQ.'N') GO TO 5                                00000032
0039               WRITE(6,                                                 00000033
0040               READ(5,                                                  00000034
0041               WRITE(6,                                                 00000035
0042               DO 1 I=1,NMAXN                                           00000036
0044               DO 1 J=1,NMAXN                                           00000037
0046               WRITE(6,                                                 00000038
0047               DO 1 K=1,NMAXN                                           00000039
0049               WRITE(6,                                                 00000040
0050          1    CONTINUE                                                 00000041
0051               WRITE(6,                                                 00000042
0052               DO 4 I=1,NMAXN                                           00000043
0054               DO 4 J=1,NMAXN                                           00000044
0056               DO 4 K=1,NMAXN                                           00000045
0058               WRITE(6,                                                 00000046
0059          4    CONTINUE                                                 00000047
0061          9    WRITE(6,                                                 00000048
0063               DO 6 I=1,NMAXN                                           00000049
0065               WRITE(6,                                                 00000050
0066               DO 6 J=1,NMAXN                                           00000051
0068               WRITE(6,                                                 00000052
0069          6    CONTINUE                                                 00000053
              C***                                                          00000054
              C***                                                          00000055
              C***DECAYED LOOP ON CASEWR                                    00000056
0071               DO 9 I=1,NMAX                                            00000057
              C***CALCULATE DAILY AVERAGE AT DESTINATION OF EACH NUCLIDE    00000058
```

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```
      [illegible]
      DO [illegible]
      DO [illegible]
   [illegible]
C****
C****INPUT INFORMATION FROM MET FILE****
C****
      JDAY=JDAY
      READ(10,600) [illegible]
  600 FORMAT([illegible])
      DO [illegible]
      IF([illegible]
      IF([illegible]
      [illegible]
  [illegible] CONTINUE
C* CHANGE
      IF([illegible] GO TO [illegible]
      IF([illegible] WRITE([illegible])
 [illegible] FORMAT(' MET DATA INPUT ERROR')
      WRITE([illegible])
 [illegible] FORMAT([illegible])
      WRITE([illegible])
 [illegible] FORMAT([illegible])
      WRITE([illegible])
 [illegible] FORMAT([illegible]
     [illegible]
     [illegible])
C* CHANGES
 [illegible] CONTINUE
      [illegible]
      DO [illegible]
      DO [illegible]
      [illegible]
      READ(10,[illegible]) [illegible]
  606 FORMAT([illegible])
      IF([illegible]
      IF([illegible]
     [illegible] WRITE([illegible]
  607 FORMAT([illegible])
      IF([illegible] WRITE([illegible]
     [illegible]
      WRITE([illegible])
  608 FORMAT([illegible])
```

```
FORTRAN IV G1  RELEASE 2.0                 [illegible]                 DATE = [illegible]          [illegible]

[illegible]      [illegible] CONTINUE
[illegible]      C***LOOP ON HOURS
[illegible]          DO 80 IHR=1,24
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      C***SUM WIND PERSISTANCE  DATA
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      C***
[illegible]      C***DO NOT ALLOW STABILITY TO VARY RAPIDLY
[illegible]      C***
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      12  [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      13  [illegible]
[illegible]      10  [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      11  [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      C*** IF STABILITY=7 THE PLUME DOES NOT GET TO THE GROUND***
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      C***
[illegible]      C***DETERMINE WIND SPEED AT TOP OF STACK AND PLUME RISE FOR EACH SOURCE
[illegible]      C***
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]          [illegible]
[illegible]      71  [illegible]
[illegible]      72  [illegible]
[illegible]          [illegible]
[illegible]      73  [illegible]
[illegible]      74  [illegible]
```

```
      [illegible]
      GO TO 78
   75 STDZ = 0.02
      GO TO 77
   76 STDZ = 0.035
   77 [illegible]
      [illegible]
   78 [illegible]
   79 CONTINUE
C***
C***LOOP ON DIRECTIONS***
C***
      DO 85 [illegible]
      [illegible]
      [illegible]
      IF([illegible]) GO TO 18
      IF([illegible]) GO TO 19
      [illegible]
      GO TO 19
   18 [illegible]
   19 [illegible]
C***
C***CALCULATE [illegible] AND CONCENTRATIONS FOR EACH DISTANCE***
C***[illegible] IS IN METERS
C***
      DO 85 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
C***LOOP ON SOURCES***
      DO 110 [illegible]
      [illegible]
      [illegible]
      [illegible]
C***IF THE SOURCE IS ABOVE THE LID, NO CONCENTRATION IS ADDED
      IF([illegible]) [illegible]
   40 [illegible]
      IF([illegible]) [illegible]
   50 [illegible]
      IF([illegible]) GO TO 251
      [illegible]
      IF([illegible]) GO TO 250
      [illegible]
      [illegible]
      IF([illegible]) [illegible]
   60 [illegible]
      GO TO 110
```

```
FORTRAN IV G1  RELEASE 2.0          MAIN          DATE = 76153          15/22/05

      70   [illegible]
     110   [illegible]
           [illegible]
     120   [illegible]
           [illegible]
           [illegible]
           [illegible]
           [illegible]
           [illegible]
           [illegible]
     170   [illegible]
           GO TO 190
     180   [illegible]
     185   [illegible]
     187   [illegible]
           GO TO 200
     195   [illegible]
     200   [illegible]
           SUM=SUM+TOT
           [illegible]
     250   [illegible]
     270   WRITE(6,9) [illegible]
       9   FORMAT([illegible]
          *[illegible]
     280   [illegible]
           GO TO 250
     251   [illegible]
           [illegible]
     252   [illegible]
     310   CONTINUE
C****SAVE MAX 1-HOUR CONC FOR THIS 24-HOUR PERIOD
C****[illegible] WHEN MAX OCCURRED
           [illegible] GO TO 31
           [illegible]
           [illegible]
           [illegible]
           [illegible]
C****ACCUMULATE 24-HOUR CONCENTRATIONS FOR EACH RECEPTOR
      31   [illegible]
C***
C****CHECK THIS DAY'S MAX 1 HOUR CONC AGAINST MAX FROM PREVIOUS DAYS
C*** AT THE SAME RECEPTOR.
C****FINAL VALUE IS MAX 1-HOUR CONC FOR EACH RECEPTOR
           [illegible] GO TO 25
           [illegible]
           [illegible]
           [illegible]
C****END OF RANGES AND AZIMUTHS
```

```
0012          35   CONTINUE
      C*****END OF 24 HOUR PERIOD
0013          30   CONTINUE
      C
      C*****OUTPUT HOURLY CONCENTRATIONS FOR THIS DAY
      C*****24 RECORDS OF NRMO HOURLY CONCENTRATIONS****
      C****
0014               DO 36 [illegible]
0015               WRITE(8) [illegible]
0016          36   CONTINUE
      C
      C*****CALCULATE 24-HOUR AVERAGES FOR EACH RECEPTOR
0017               [illegible]
0018               [illegible]
0019               [illegible]
0020               [illegible]
0021               [illegible]
0022               [illegible] GO TO 35
0023               [illegible]
0024               [illegible]
0025               [illegible]
      C
      C*****SAVE DAILY AVERAGES****
      C
      C*****CHECK THIS DAY'S MAX CONC AGAINST PREVIOUS 24-HOUR MAX,
      C*****FINAL VALUE IS MAX 24 HOUR CONC FOR EACH RECEPTOR
      C
0026          60   IF([illegible]) GO TO 33
0027               [illegible]
0028               [illegible]
      C
      C*****SUM DAILY AVERAGES FOR CALCULATION OF ANNUAL MEAN
      C
0029          33   [illegible]
      C*****COMPUTE WIND PERSISTANCE
0030               [illegible]
0031               [illegible]
0032               RATIO=[illegible]
      C
      C*****OUTPUT DAILY CONCENTRATIONS
      C*****1 RECORD OF NRMO 24-HOUR CONCENTRATIONS****
      C
0033               WRITE(9) [illegible]
      C
      C*****OUTPUT MAX 1-HOUR CONC AND HIGHEST 24-HOUR CONC AT ANY RECEPTOR
                   WRITE([illegible]) [illegible]
                 1 RATIO,[illegible]
0034         601   FORMAT([illegible])
```

```
0836          WRITE(10,8006) (UT,(WMAXT,K=1,NROUTR),MUN,(WMAXT,MEN,NROUTR),
0836      8006 FORMAT(' DATE [1,2,3]  MAX HOURLY CONC=',(PE13.6,'  DIRECTION=',
                F12.1,'  DISTANCE=',I3,'DEG.',I3,' MN  HOURLY',(F13.1,F12.
                8(PE13.6,'  DIRECTION=',F6.1,'  DISTANCE=',
                F10.1,' KM',
                WRITE(10,8007) MATEO,PERST
0837          8007 FORMAT(' MATEO=',F8.3,' PERSIST=',F8.3/)
0838          IF(WMAXT.LE.WMAXTR(I)) GO TO 85
0839          WMAXTR(I)=WMAXT
0840          WMAXTR(2)=MEN
0841          WMAXTR(3)=MUN(MAJ)
0842          WMAXTR(4)=UT
0843          WMAXTR(5)=MEN
0844          85  IF(WMAXT.LE.WMAXTR(I)) GO TO 90
0845          WMAXTR(1)=WMAXT
0846          WMAXTR(2)=MEN
0847          WMAXTR(3)=MUN(MAJ)
0848          WMAXTR(4)=UT
0849          WMAXTR(5)=MEN
              CCCCEND DAILY LOOPCCC
0850          90  CONTINUE
              C
              CCCCCALCULATE ANNUAL MEANS AND DETERMINE THE MAXIMUM
              CCCC
0851          AMMAX=0.0
0852          MAXI=0
0853          MAXJ=0
0854          DO 91 I=1,30
0855          DO 91 J=1,MSTA
0856          IF(I.GE.J) GO TO 91
0857          CONTINUE
0858          IF(AMMAX.LE.AMMAX) GO TO 91
0859          AMMAX=CONC(I,J)
0860          MAXI=I
0861          MAXJ=J
0862          91  CONTINUE
              C
              CCCCWRITE ANNUAL MEAN AT EACH RECEPTOR AND POINT RECEPTOR WITH HIGHEST
              CCCC  ANNUAL MEAN CONCENTRATION
              CCCC( RECORD OF GROUND MEAN ANNUAL CONCENTRATIONSCCC
              CCCC
0863          WRITE(10,1101)(I,I=1,NROUT)
              CCCCFUNCO UNMAXR,UNMAXV I AMMAX, HOURLY,DAILY & YEARLY MAXIMA FOR THE YE
              C  WRITE(10,7101) UNMAXR,(UNMAXV
0864          7101 FORMAT(' MAX HOURLY ',(PE13.6,5X,0PF5.0,0PF5.1,0PF5.0,TR1,5A4))
              C  WRITE(10,7101) UNMAXR,(UNMAXV
0865          7101 FORMAT(' MAX DAILY  ',(PE13.6,5X,0PF5.0,0PF5.1,0PF5.0,TR1,5A4)
              C  WRITE(10,7101) AMMAX,MAXI,MAXJ,(UNMAXV,I=1,5)
0866          7101 FORMAT(' MAX ANNUAL ',(PE13.6,5X,0PF5.0,0PF5.1,0PF5.0,TR1,5A4)
```

```
                C     DO 700 I=1,50
                C     WRITE(10,700) I,(CHI(I,J),J=1,5),(DHI(I,J),J=1,5),(DHI(I,J),J=6,7)
 0047            700  FORMAT(I5,10(1X,E11.4))
                C     WRITE(10,704) (CHI(I,J),J=1,5),(DHI(I,J),J=6,7)
 0048            704  FORMAT(10(1X,E11.4))
 0049            700  CONTINUE
                C     WRITE MAX ANNUAL MEANS
 0050                 WRITE(10,5500) TITLE
 0051                 WRITE(10,7001) AMMAX,MAXI,RNO(MAXI)
 0052            700  FORMAT(/5X,'      MAXIMUM MEAN CONC=',1PE12.4,' DIRECTION=',
                     E14.4,' DISTANCE=',0PF5.1,' KM'//)
                C
                C     PRINT ANNUAL MEANS
                C
 0053                 WRITE(10,800) (NDIRECT(J),J=1,5)
 0054            800  FORMAT(/5X,'      ANNUAL MEAN CONCENTRATION AT EACH RECEPT
                     ORS'/15X,5I7,'RANGE',1X,'DIST',1X,'DIR'
                     DO 820 I=1,35
                     WRITE(10,801) I,(CHI(I,J),J=1,5),(DHI(I,J),J=1,5)
 0055            801  FORMAT(I5,5(1X,E10.4),1P5E15.3)
 0056            820  CONTINUE
                C
                C     PRINT HIGHEST 24-HOUR CONCENTRATION FOR THE YEAR AT EACH RECEPTOR
 0057                 WRITE(10,5500) TITLE
 0058                 WRITE(10,7001) AMMAX
 0059            705  FORMAT(/5X,'YEARLY MAXIMUM 24-HOUR CONC=',1PE12.4,' DIRECTION=',
                     0PF5.0,' DISTANCE=',0PF5.1,' KM',' DAY=',0PF5.0,' MONTH=',
                     0PF5.0/15X
 0060                 WRITE(10,810) (NDIRECT(J),J=1,5)
 0061            810  FORMAT(/5X,'      HIGHEST 24-HOUR CONCENTRATION AT EACH RECE
                     PTOR'/15X,5I7,'RANGE',1X,'DIST',1X,'DIR'
                     DO 821 I=1,35
 0062                 WRITE(10,801) I,(CHI(I,J),J=1,5),(DHI(I,J),J=1,5)
 0063            821  CONTINUE
                C
                C     PRINT HIGHEST 1-HOUR CONCENTRATIONS FOR THE YEAR AT EACH RECEPTOR
 0064                 WRITE(10,5500) TITLE
 0065                 WRITE(10,7001) AMMAX
 0066            701  FORMAT(/5X,'YEARLY MAXIMUM 1-HOUR CONC=',1PE12.4,' DIRECTION=',
                     0PF5.0,' DISTANCE=',0PF5.1,' KM',' DAY=',0PF5.0,' HOUR=',
                     0PF5.0/15X
 0067                 WRITE(10,820) (NDIRECT(J),J=1,5)
 0068            820  FORMAT(/5X,'      HIGHEST 1-HOUR CONCENTRATION AT EACH RECE
                     PTOR'/15X,5I7,'RANGE',1X,'DIST',1X,'DIR'
                     DO 822 I=1,35
 0069                 WRITE(10,801) I,(CHI(I,J),J=1,5),(DHI(I,J),J=1,5)
```

```
FORTRAN IV 31  [illegible]
0291          602  [illegible]
0296               [illegible]
0299          604  [illegible]
0300          422  CONTINUE
0301               CALL EXIT
0302               END
```

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```
FORTRAN IV G1  [illegible]                  [illegible]                  [illegible]
0001                 SUBROUTINE SIGMA1 (X,XY,KST,SY,SZ)
                C SUBROUTINE TO CALCULATE SIGMA Y AND SIGMA Z USING F.R.SMITH'S METHOD
                C (SMITH=SIGMA Z,PASQUILL=SIGMA Y)
0002                 GO TO (10,20,30,40,50,60),KST
                C  STABILITY A(10)
0003                 10 TH = (24.167 - 2.[illegible]*ALOG(XY))/57.2958
0004                    SZ=.112*(X*1000.)**.06711.+.000538*(X*1000.)**.[illegible]
0005                    GO TO 71
                C  STABILITY B(20)
0006                 20 TH = (19.333 - 1.[illegible]*ALOG(XY))/57.2958
0007                    SZ=.135*(X*1000.)**.[illegible]
0008                    GO TO 71
                C  STABILITY C(30)
0009                 30 TH = (12.5 - 1.[illegible]*ALOG(XY))/57.2958
0010                    SZ=.112*(X*1000.)**.[illegible]
0011                    GO TO 71
                C  STABILITY D(40)
0012                 40 TH = (9.[illegible]*ALOG(XY))/57.2958
0013                    SZ=.[illegible]*(X*1000.)**.[illegible]
0014                    GO TO 71
                C  STABILITY E(50)
0015                 50 TH = (6.25 - 0.[illegible]*ALOG(XY))/57.2958
0016                    SZ=.[illegible]*(X*1000.)**.[illegible]
0017                    GO TO 71
                C  STABILITY F(60)
0018                 60 TH = (5.[illegible] - 0.[illegible]*ALOG(XY))/57.2958
0019                    SZ=.[illegible]*(X*1000.)**.[illegible]
0020                 71 SY = 1000. * XY * SIN(TH)/(2.15 * COS(TH))
0021                    RETURN
0022                    END
```

```
FORTRAN IV G1  RELEASE 2.0          SIGMA          DATE = 76156        12/06/10

0001              SUBROUTINE SIGMA(X,XY,RST,SY,SZ)
0002              PRST=FLOAT(RST)/10.
0003              RST1=PRST
0004              RST2=RST1-1
0005              IF(RST2.LT.1) RST1=1
0006              IF(RST2.GT.1) RST2=1
0007              CALL SIGMA(X,XY,RST1,SY1,SZ1)
0008              CALL SIGMA(X,XY,RST2,SY2,SZ2)
0009              DY=SY2-SY1
0010              DZ=SZ2-SZ1
0011              DR=PRST-RST1
0012              SY=SY1+DR*DY
0013              SZ=SZ1+DR*DZ
0014              RETURN
0015              END
```

[illegible]

[illegible]

[illegible]

APPENDIX C

CONCENTRATION PROFILES FOR THE CANAL AND MUSKINGUM PLANTS FOR DIFFERENT SETS OF DISPERSION CURVES

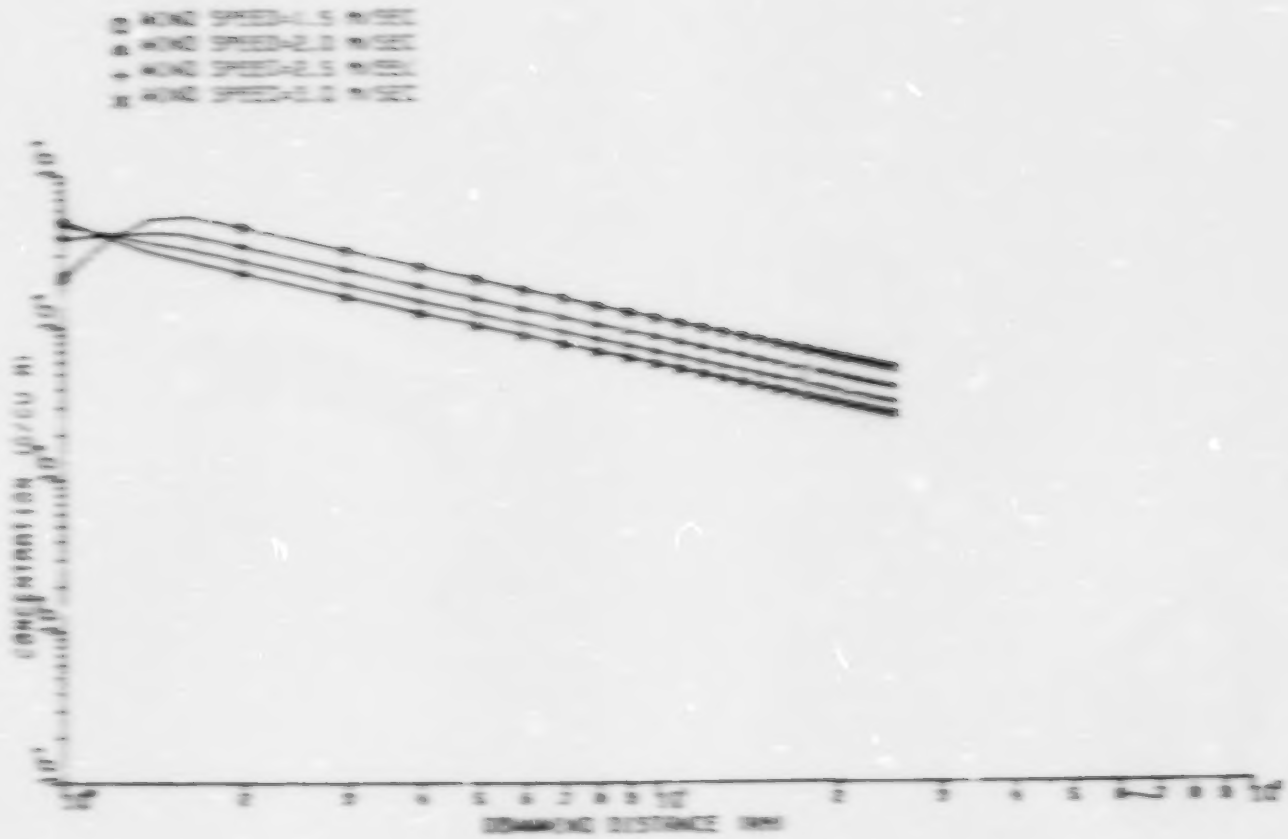

Figure C-1a. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

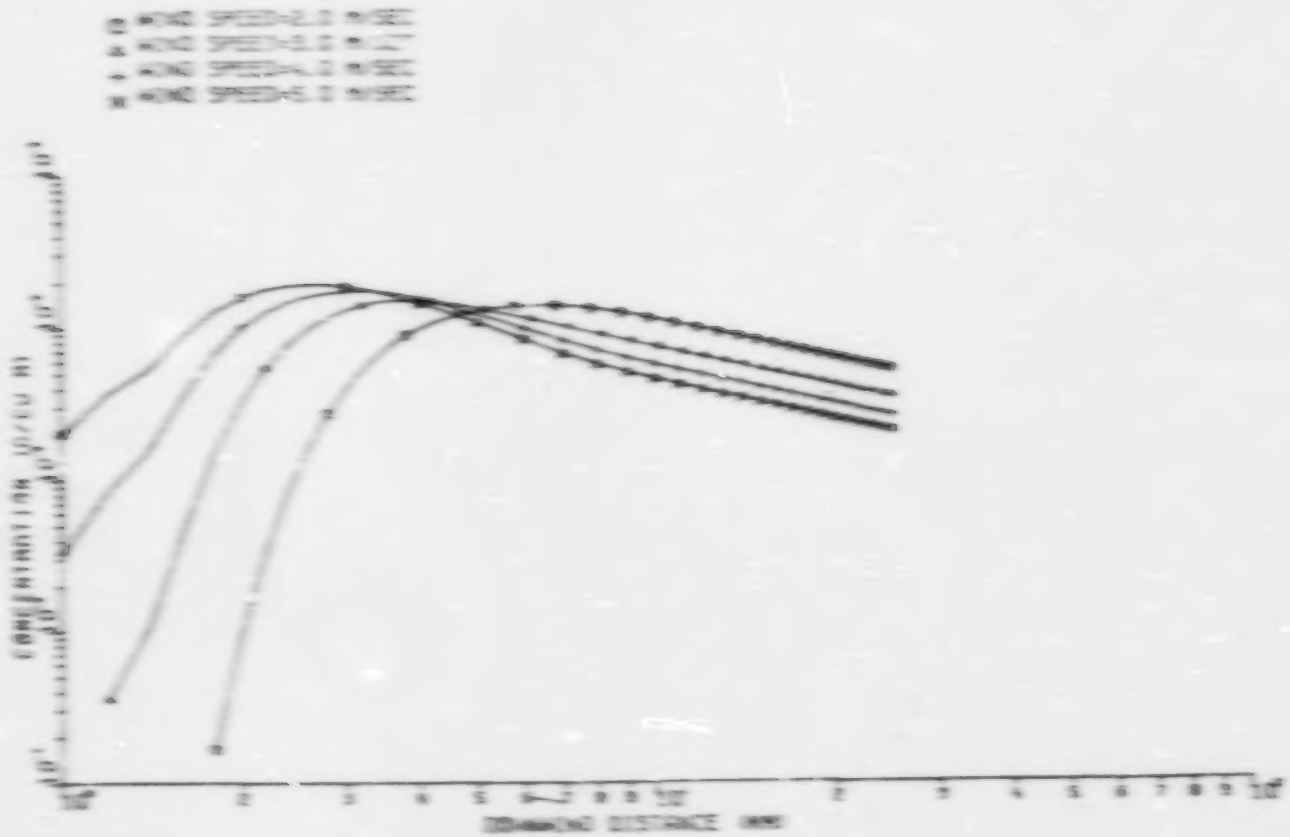

Figure C-3b. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

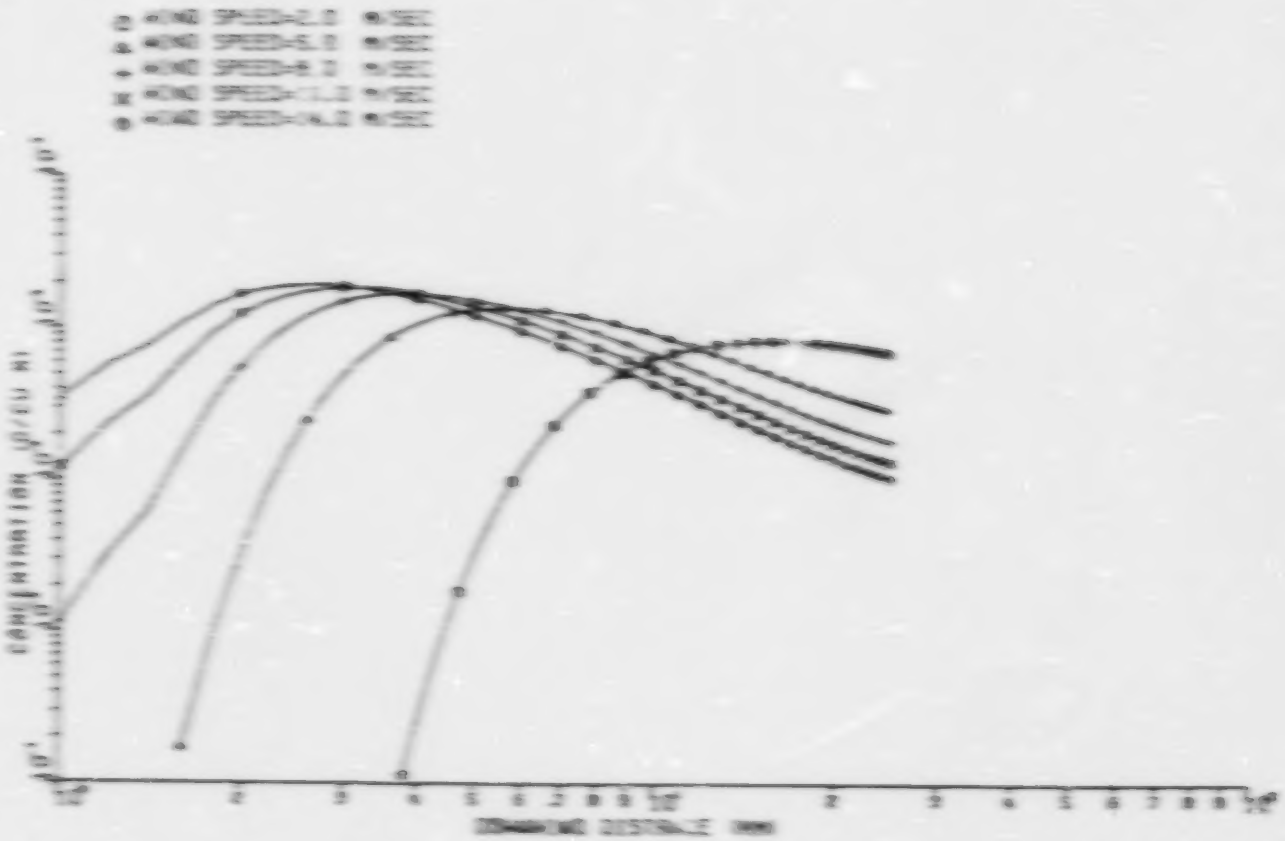

Figure C-1c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

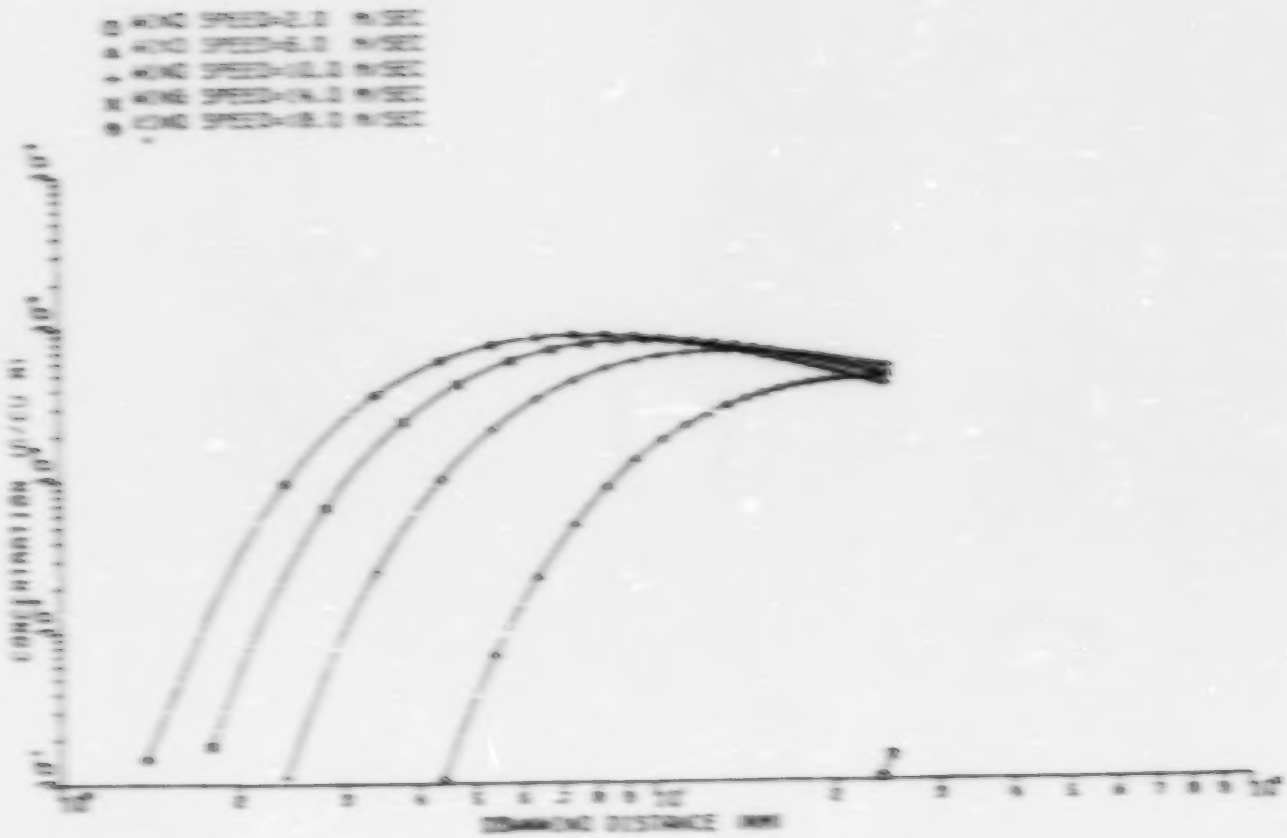

Figure C-16. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

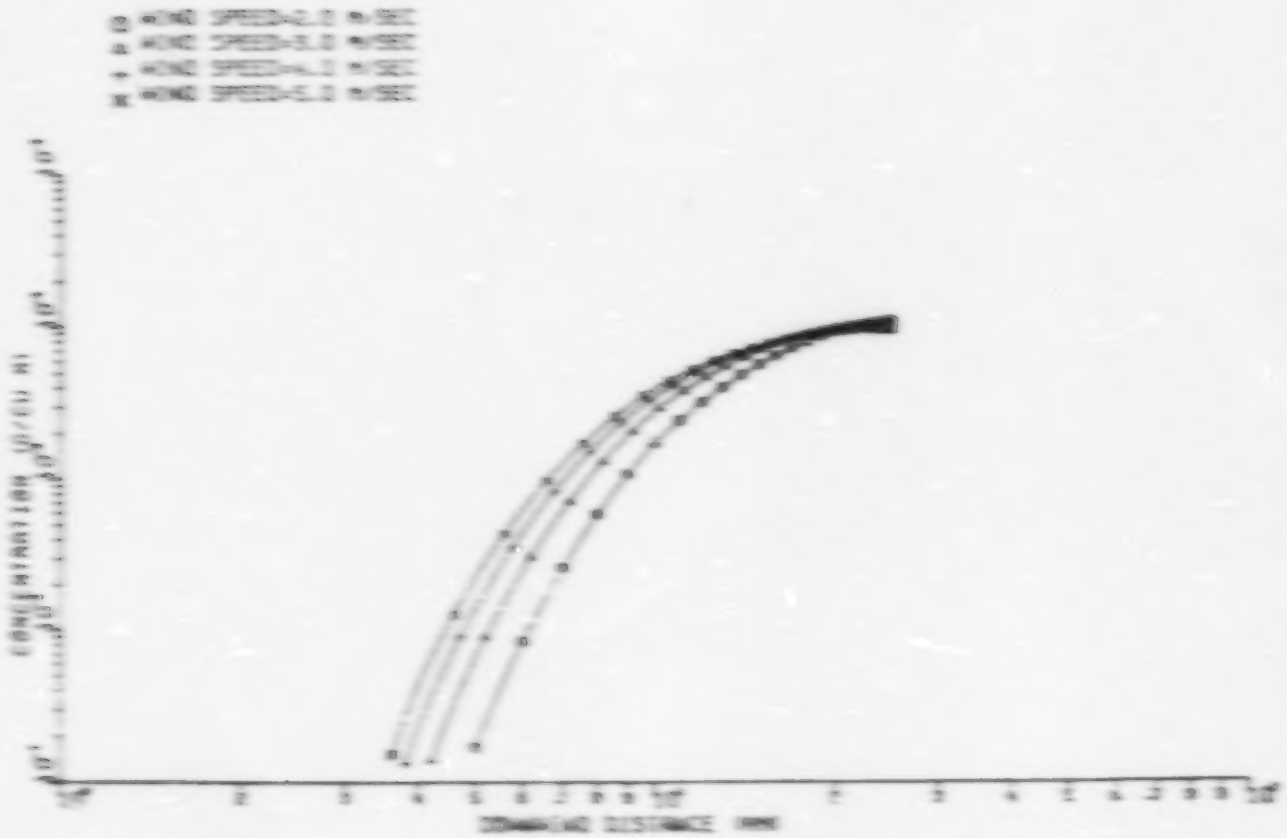

Figure C-1a. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

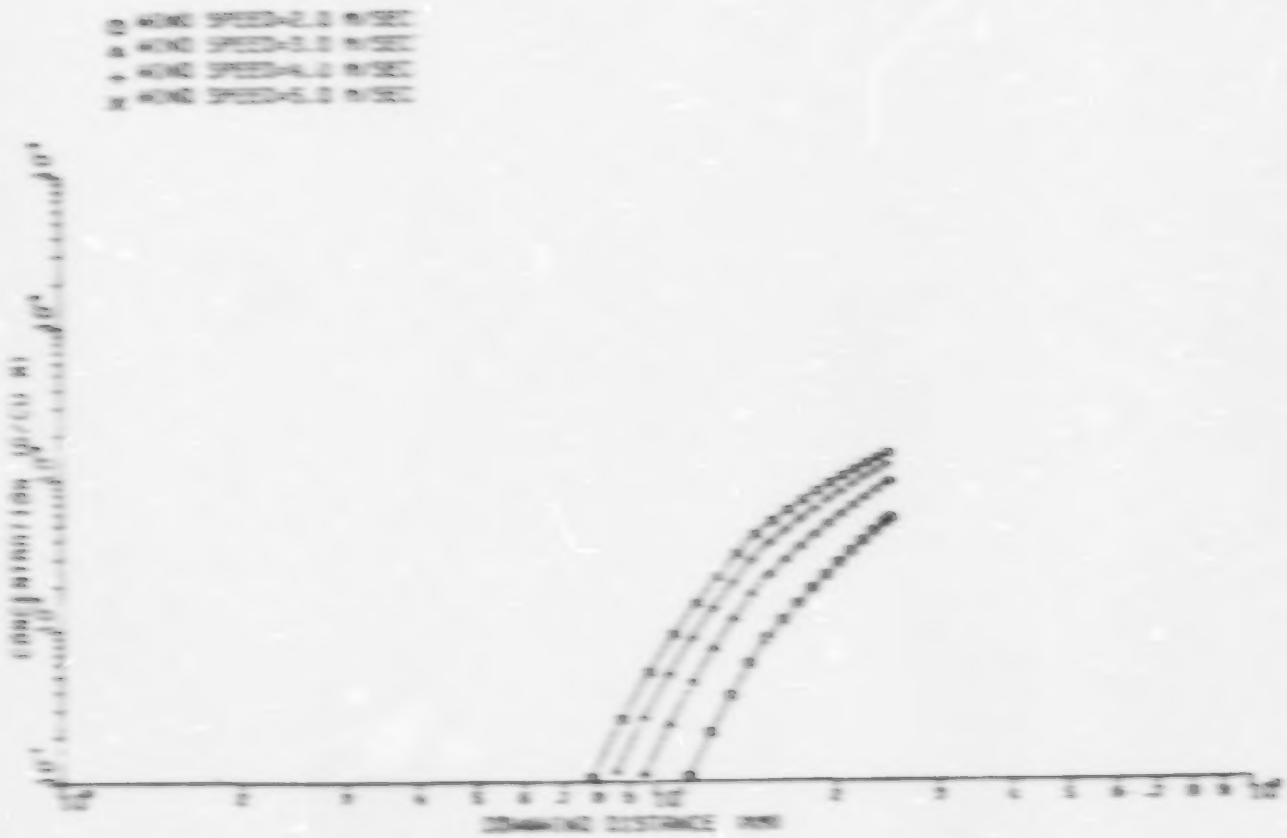

Figure C-11. Plume centerline concentration versus downwind distance for stability Class F at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

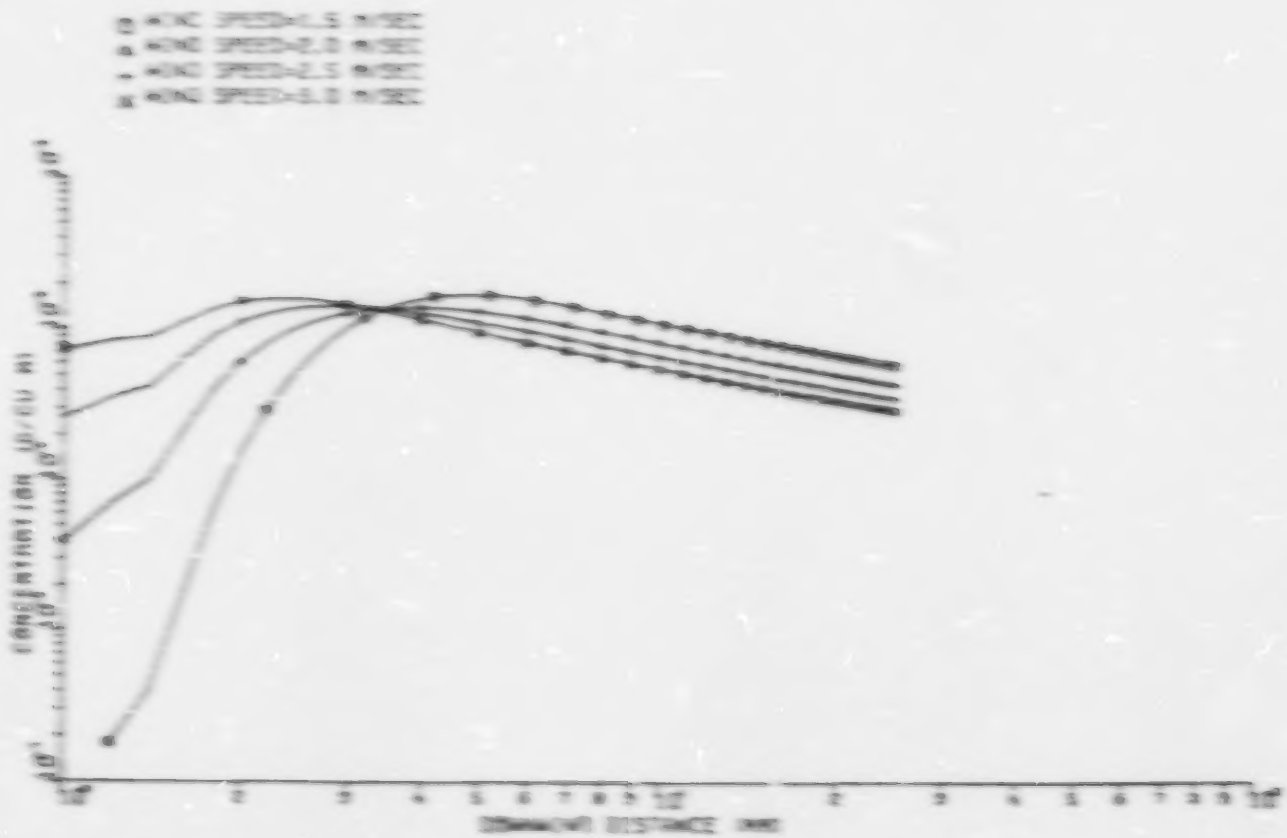

Figure C-2c. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plume. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

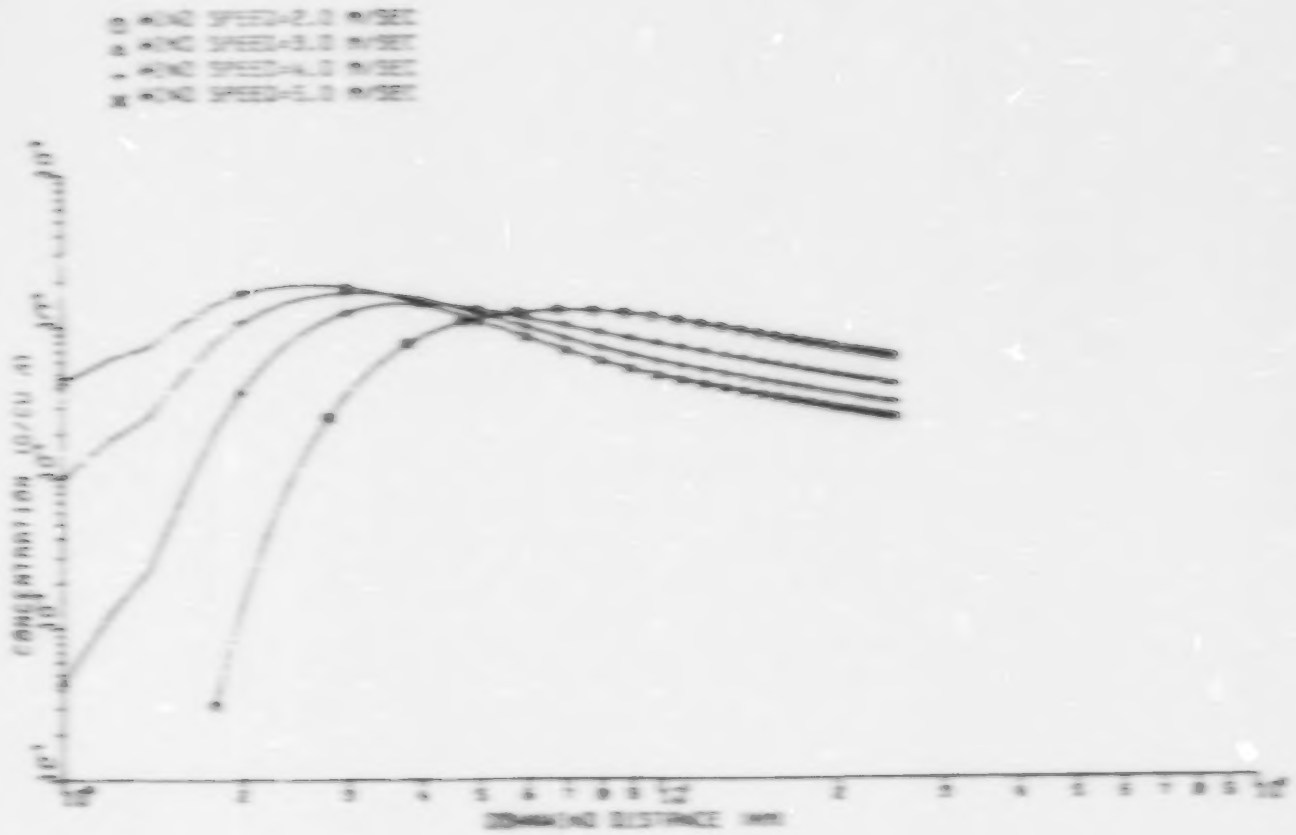

Figure C-4b. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

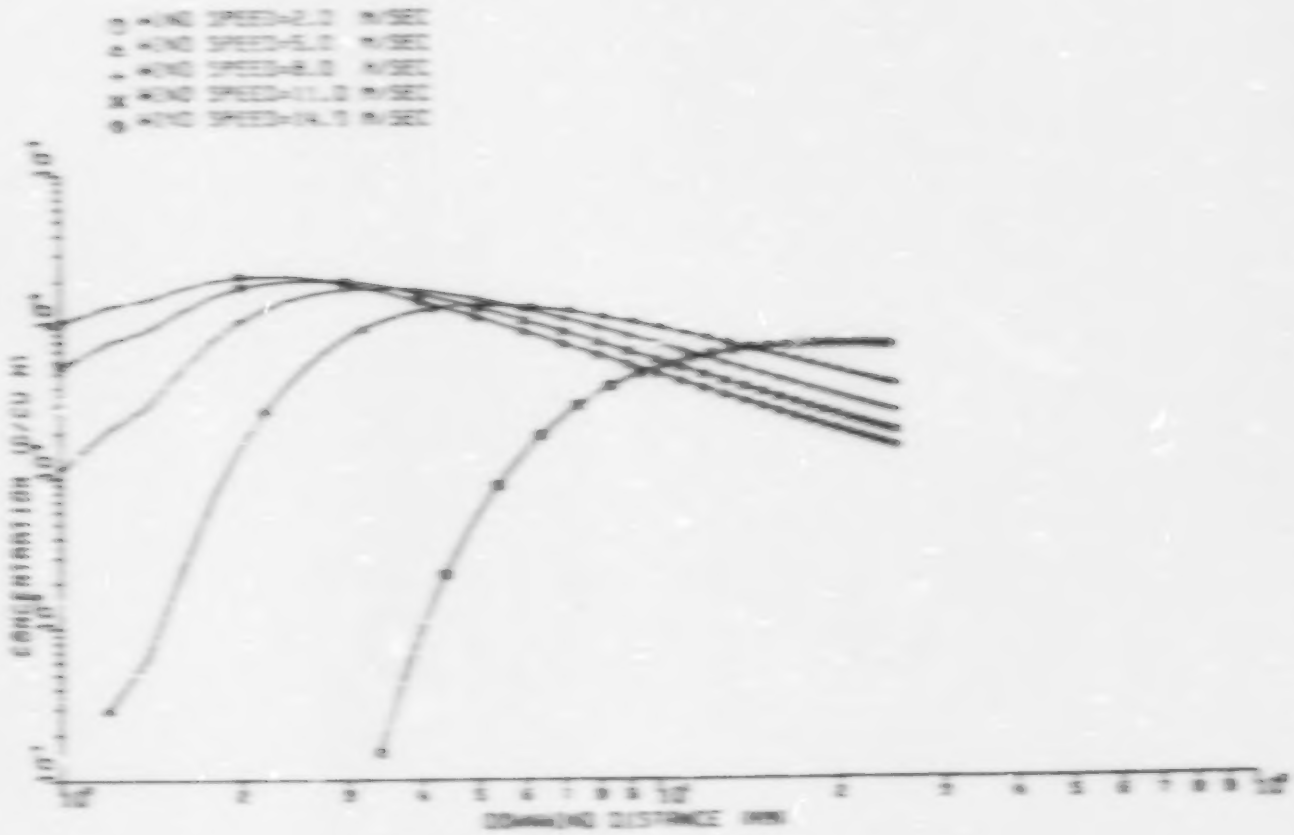

Figure C-2c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

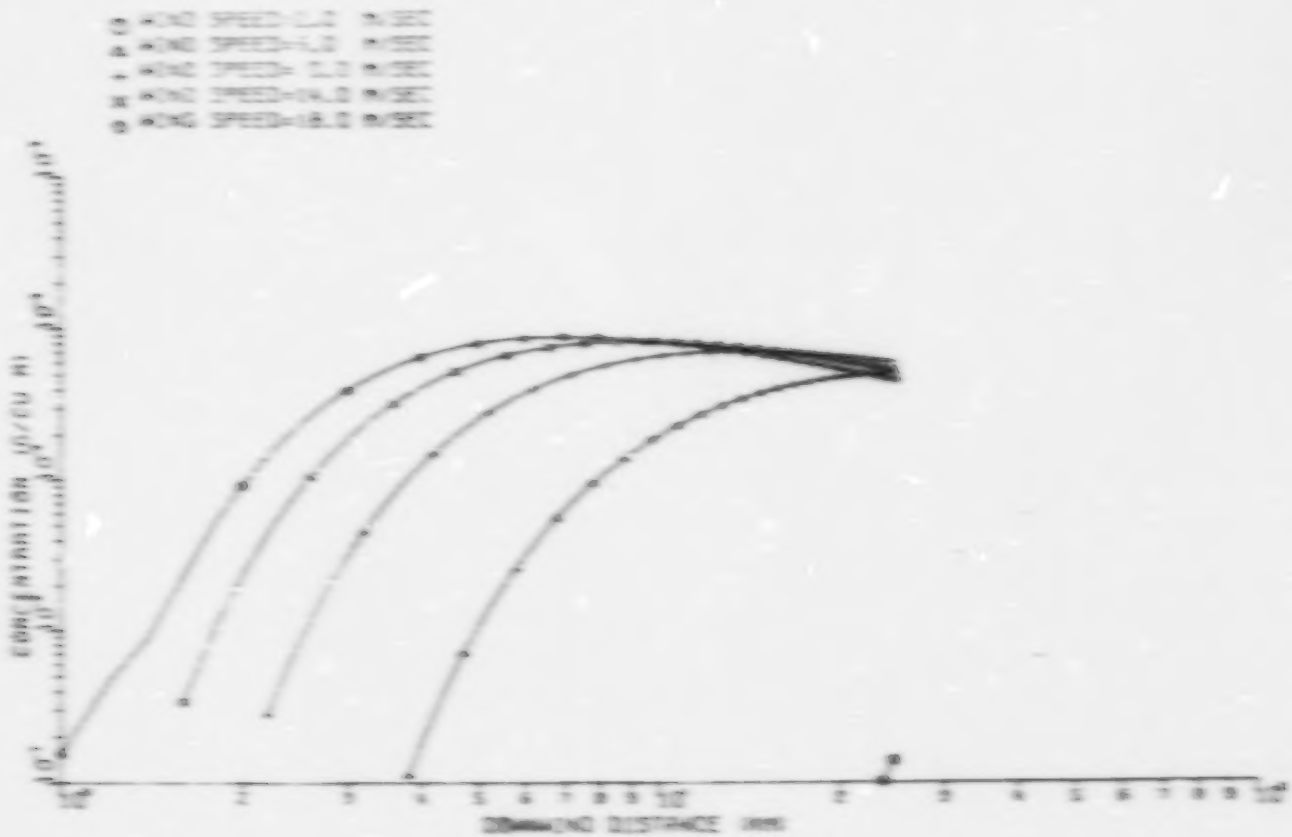

Figure C-26. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

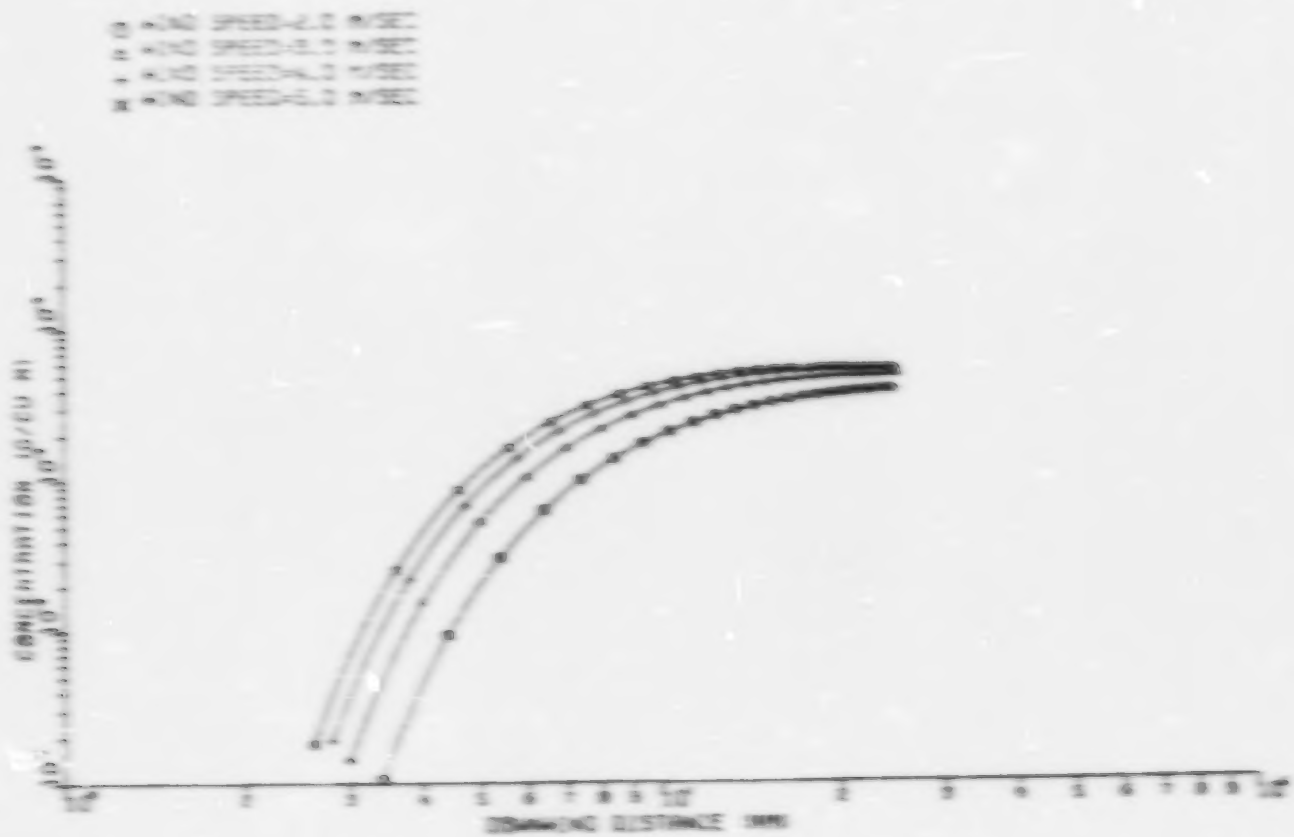

Figure C-2e. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

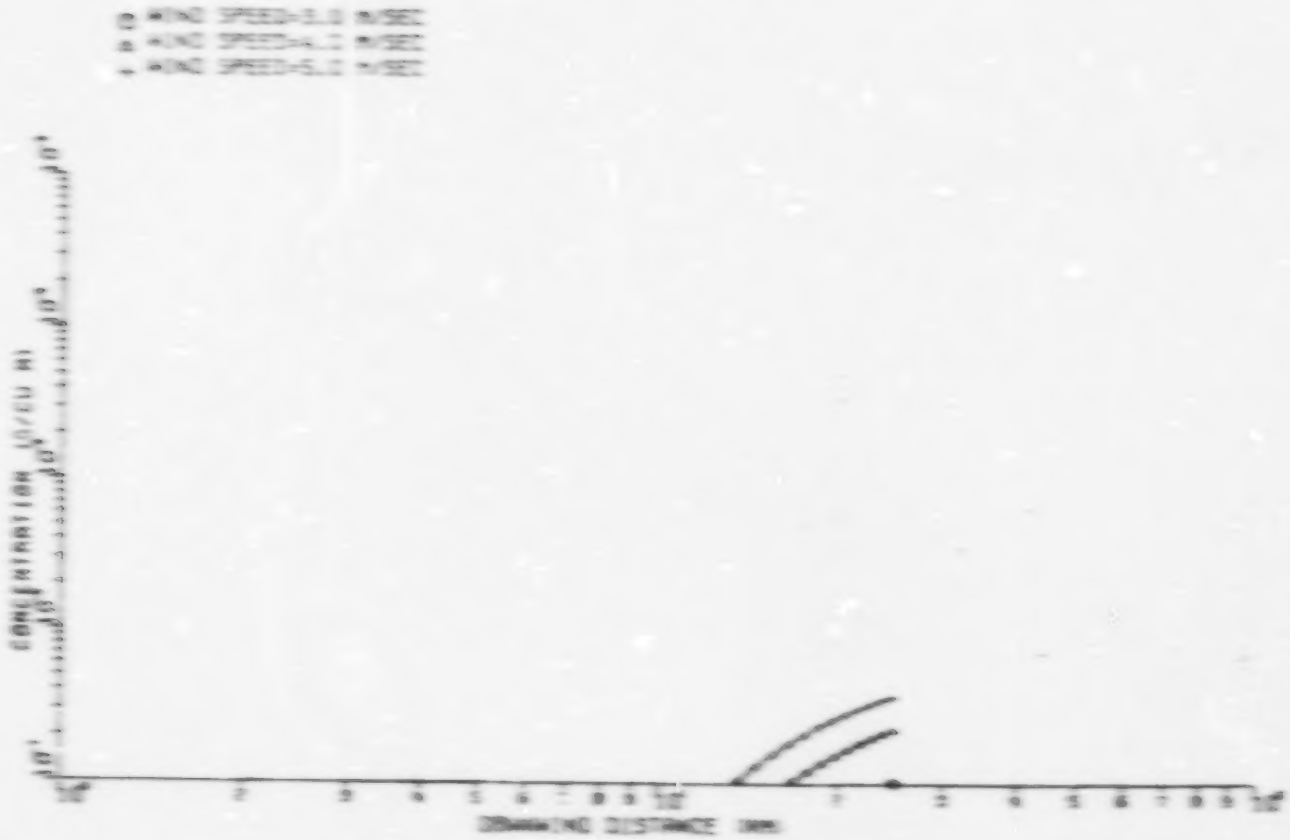

Figure C-21. Plume centerline concentration versus downwind distance for stability Class F at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

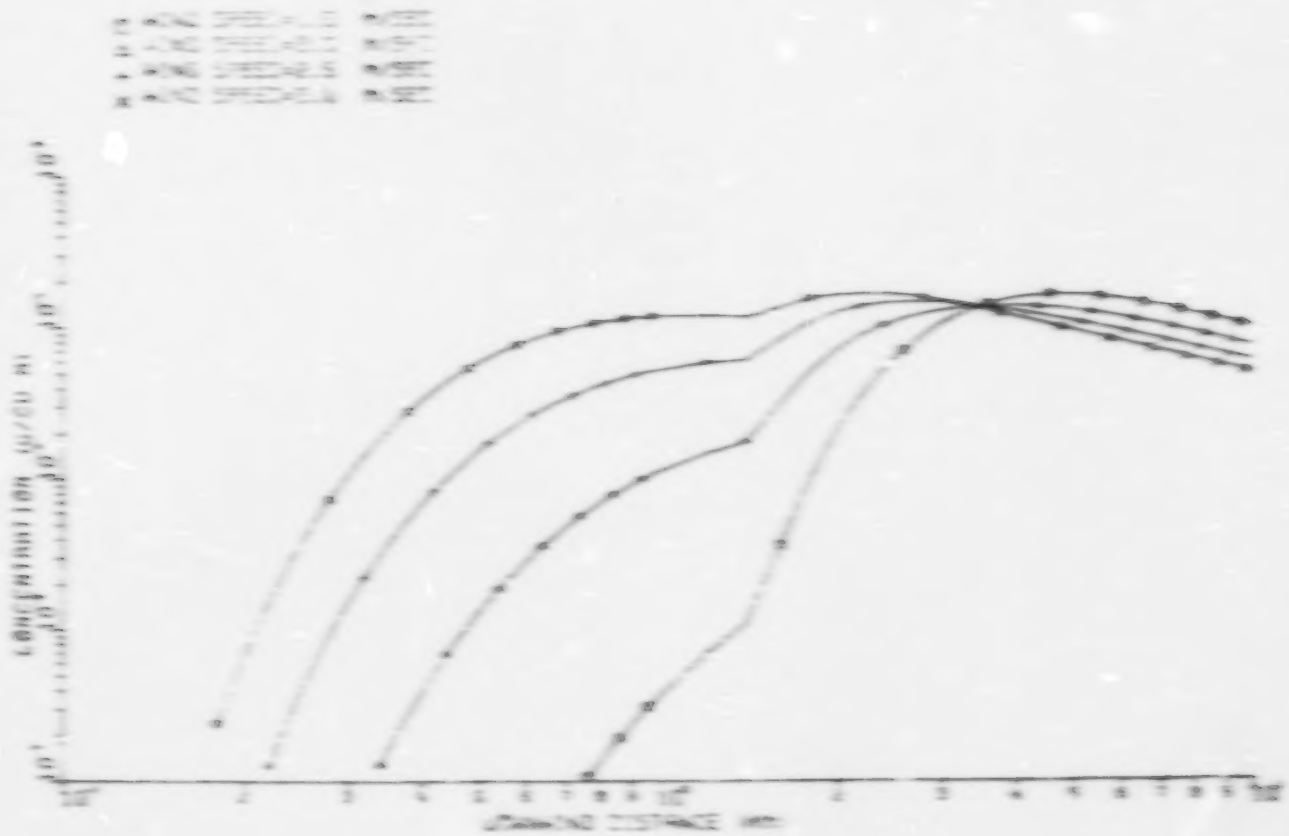

Figure C-3a. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

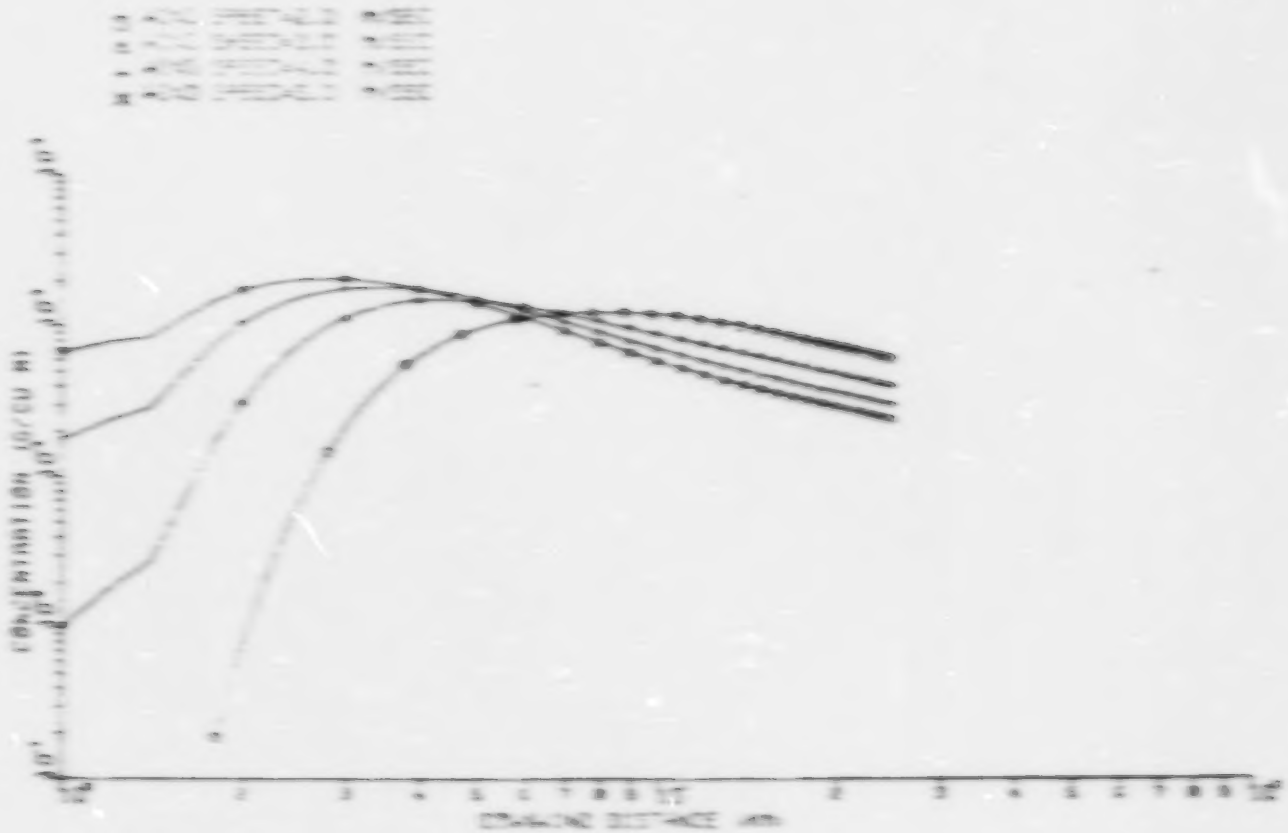

Figure C-3. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

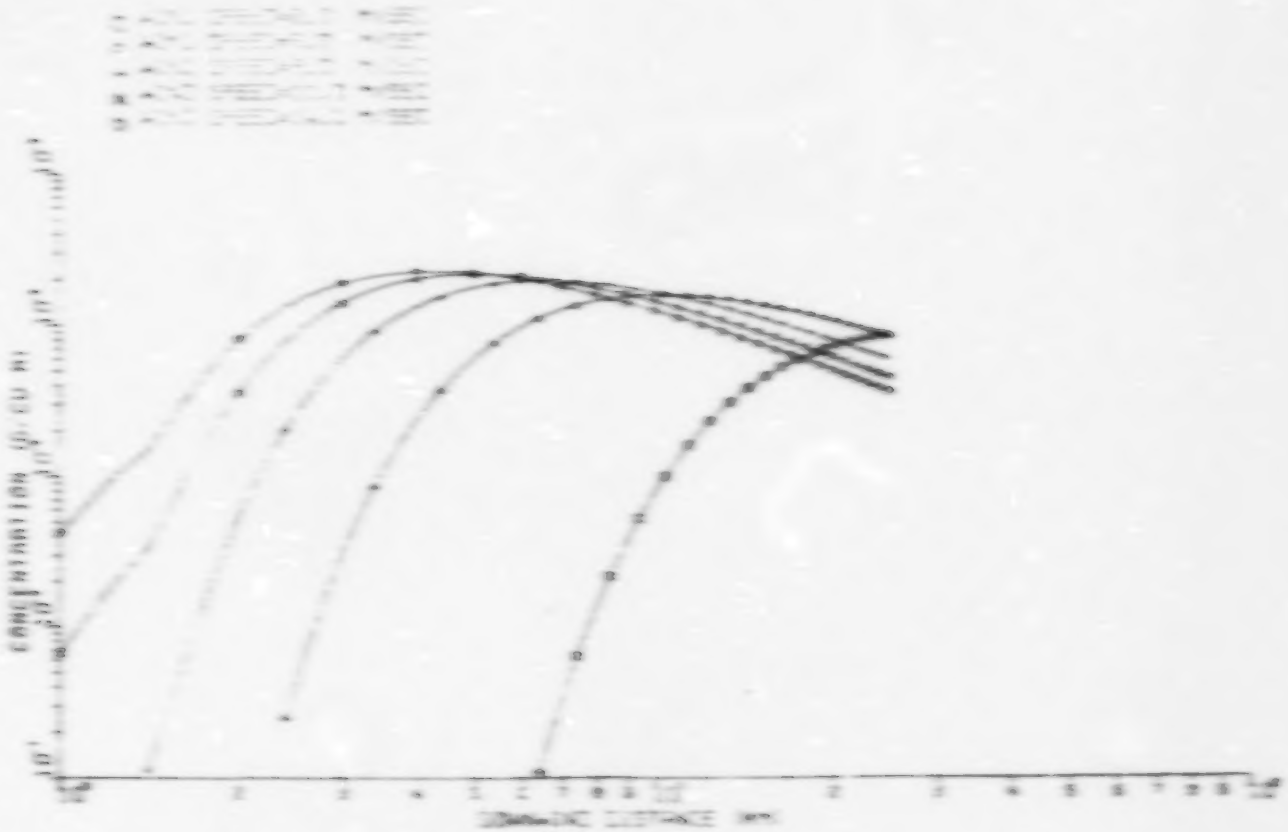

Figure C-3c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

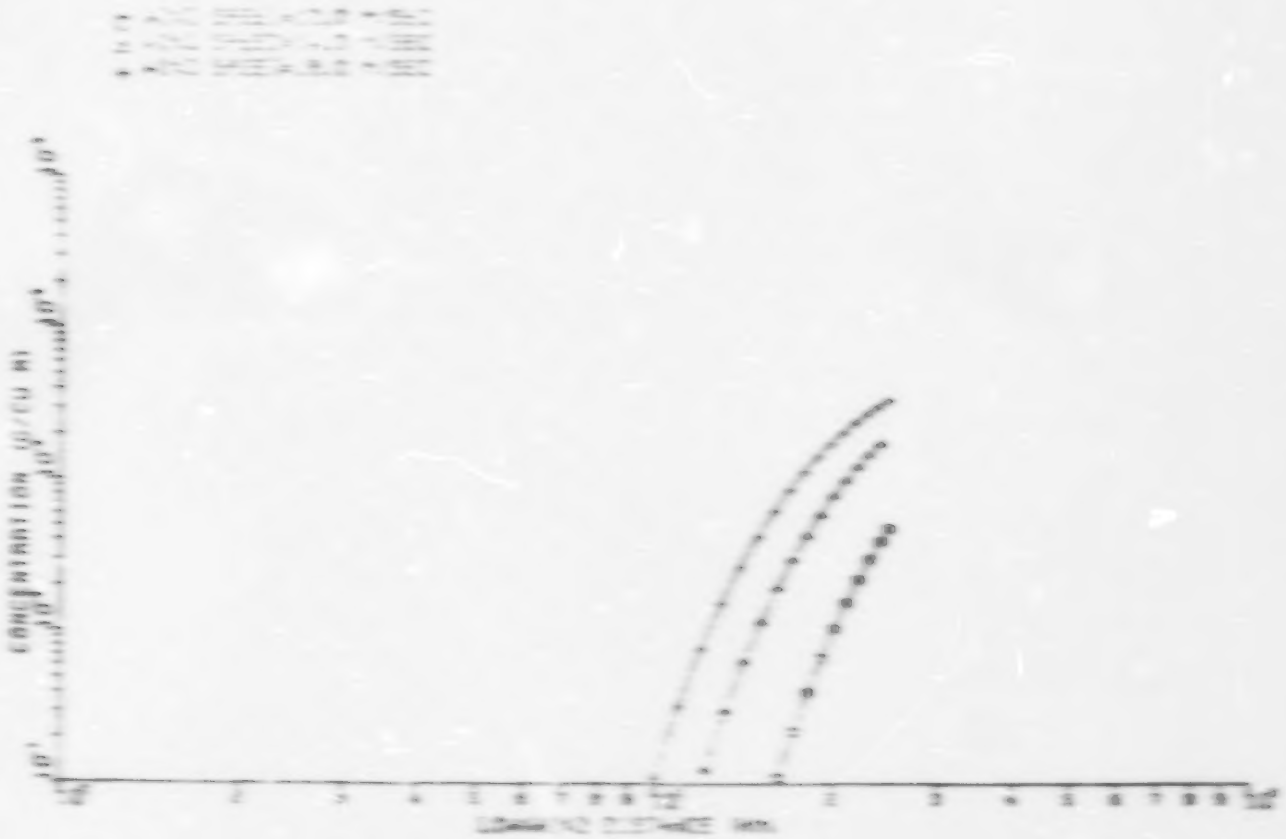

Figure C-36. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

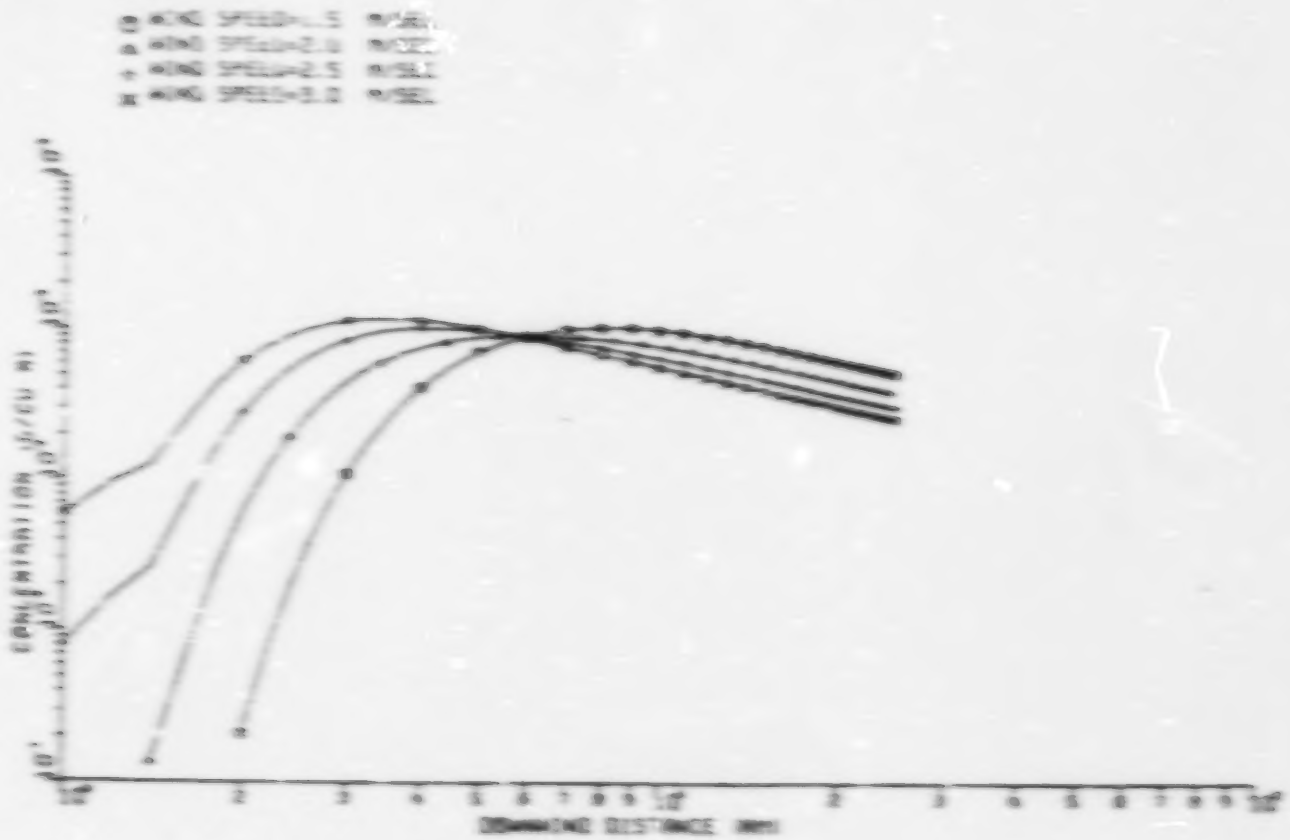

Figure C-4a. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

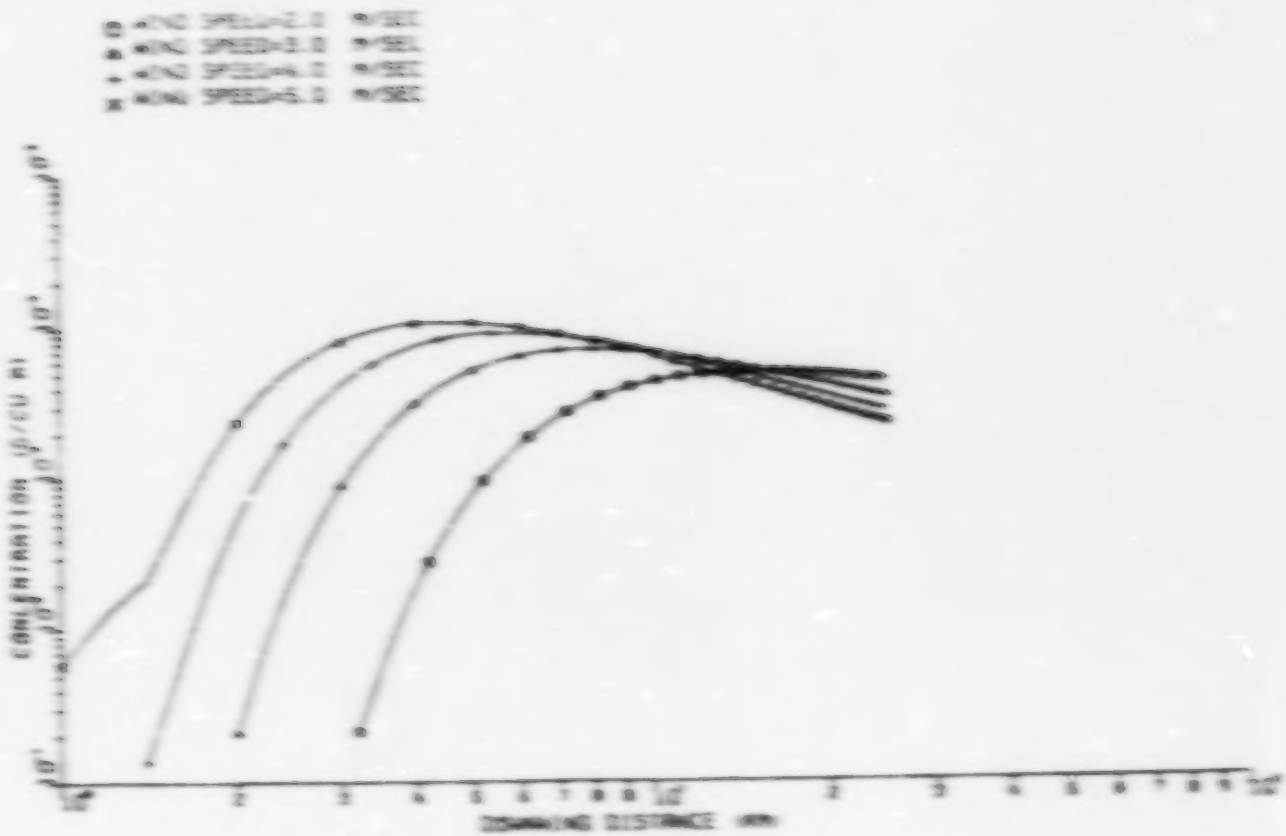

Figure C-46. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

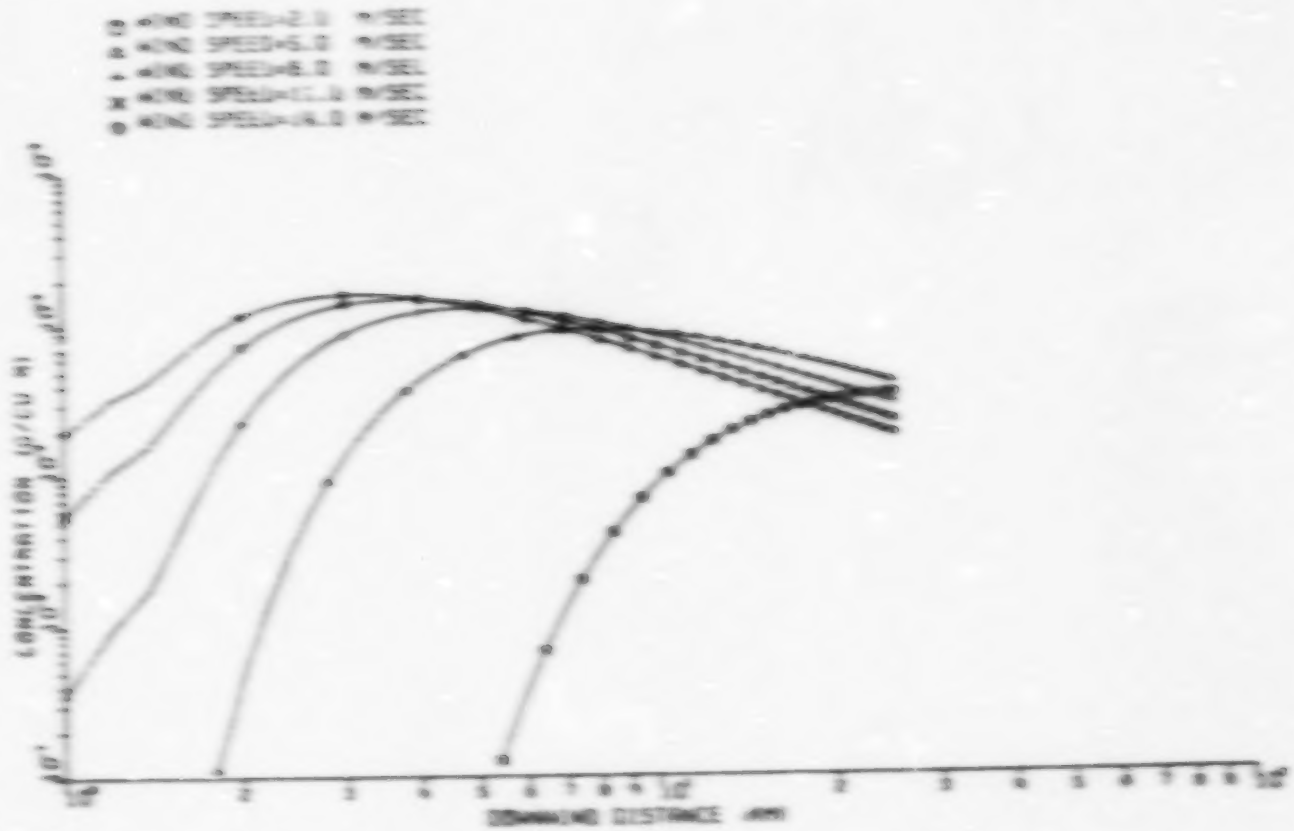

Figure C-4c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

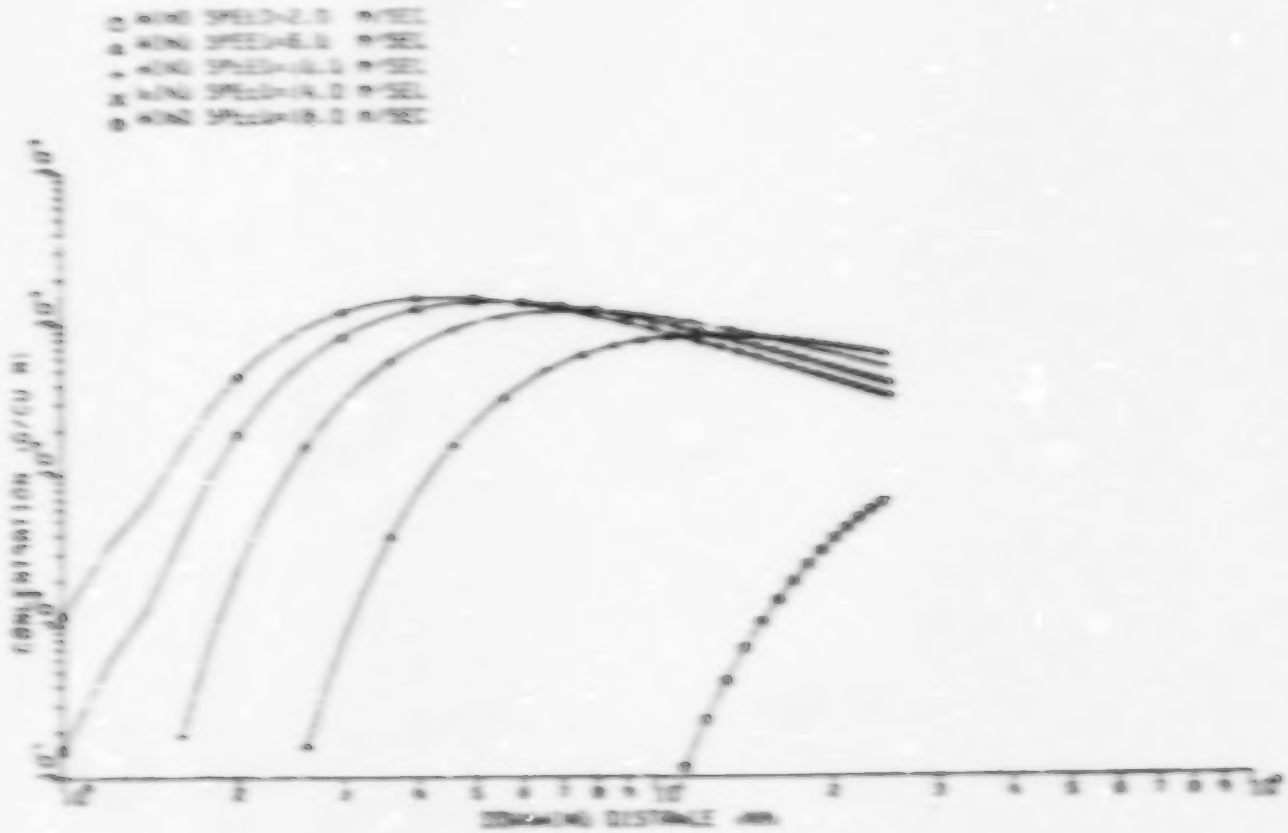

Figure C-4d. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

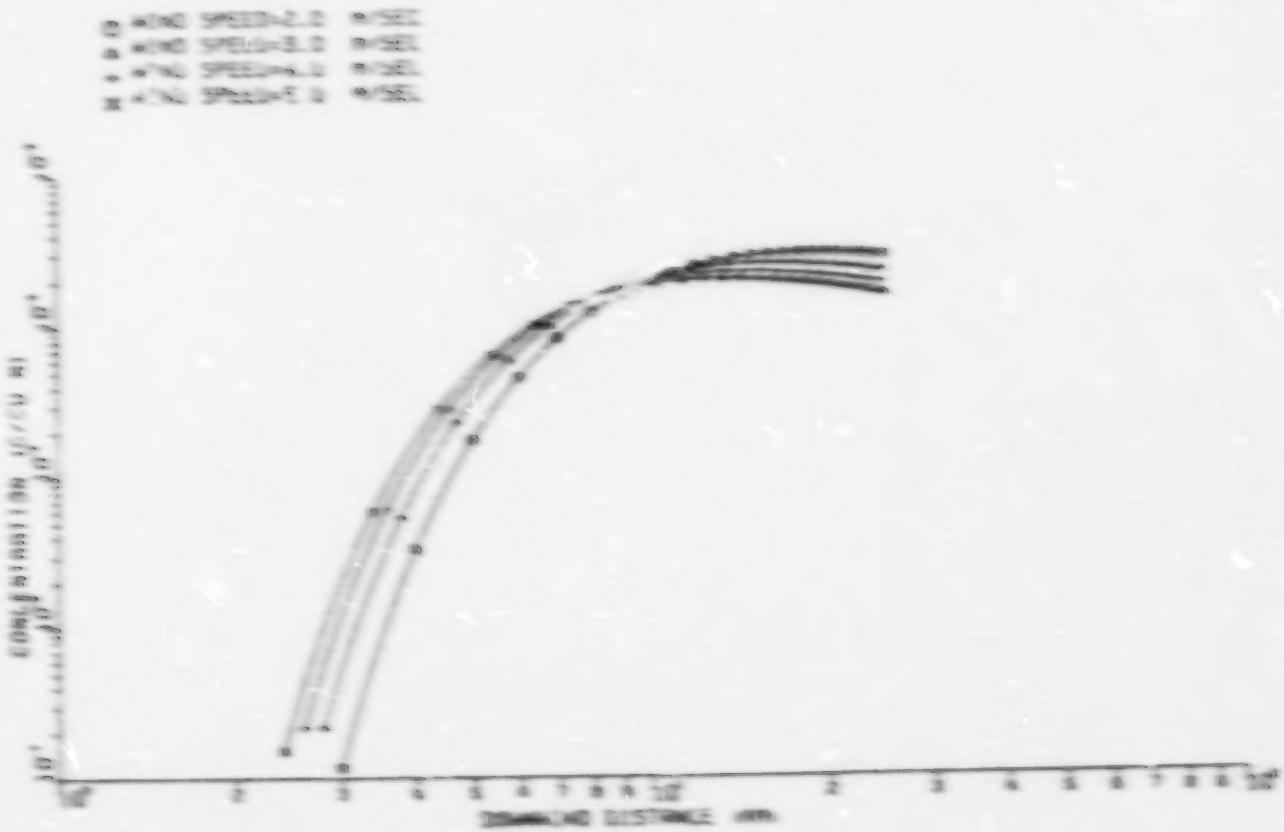

Figure C-4a. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. F. B. Smith σ_z and Pasquill-Gifford σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

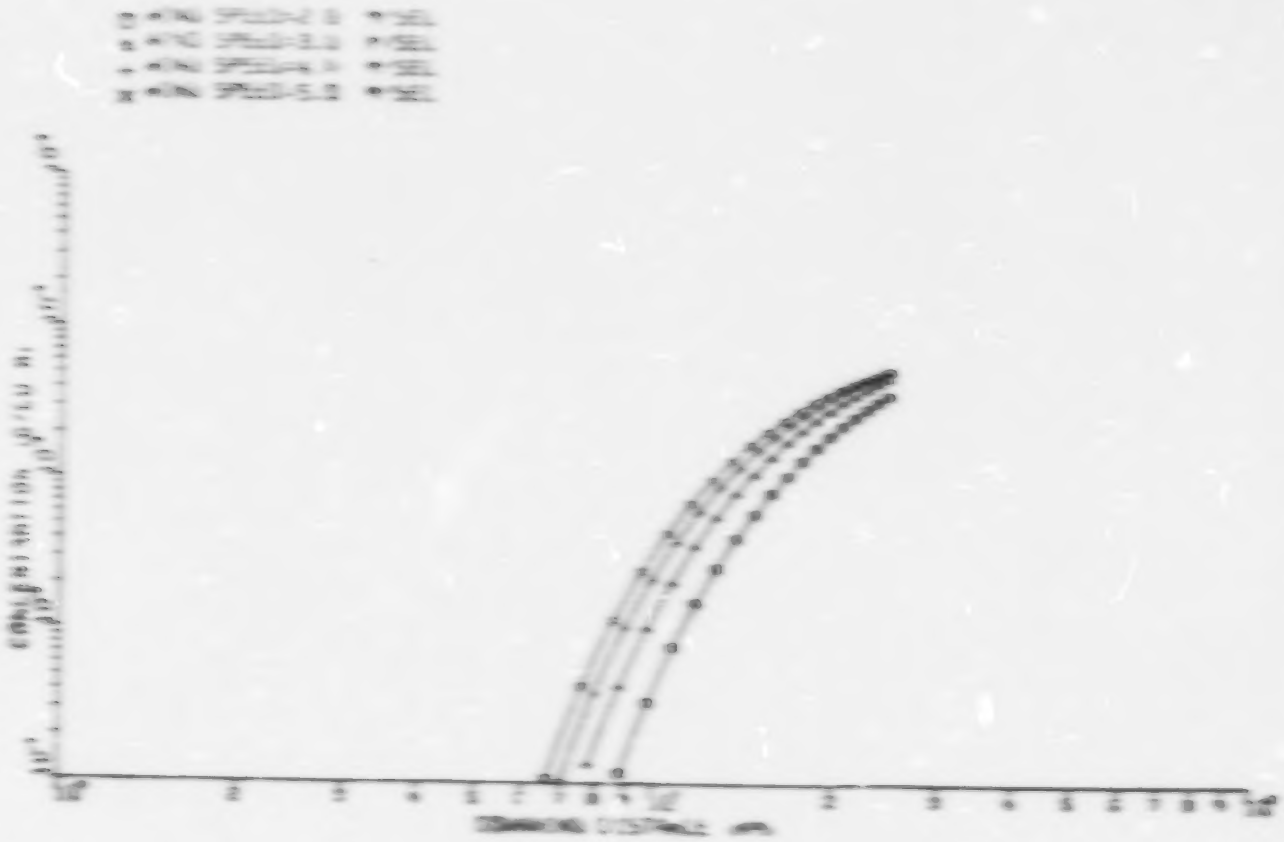

Figure C-4C. Plume centerline concentration versus downwind distance for stability Class F at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

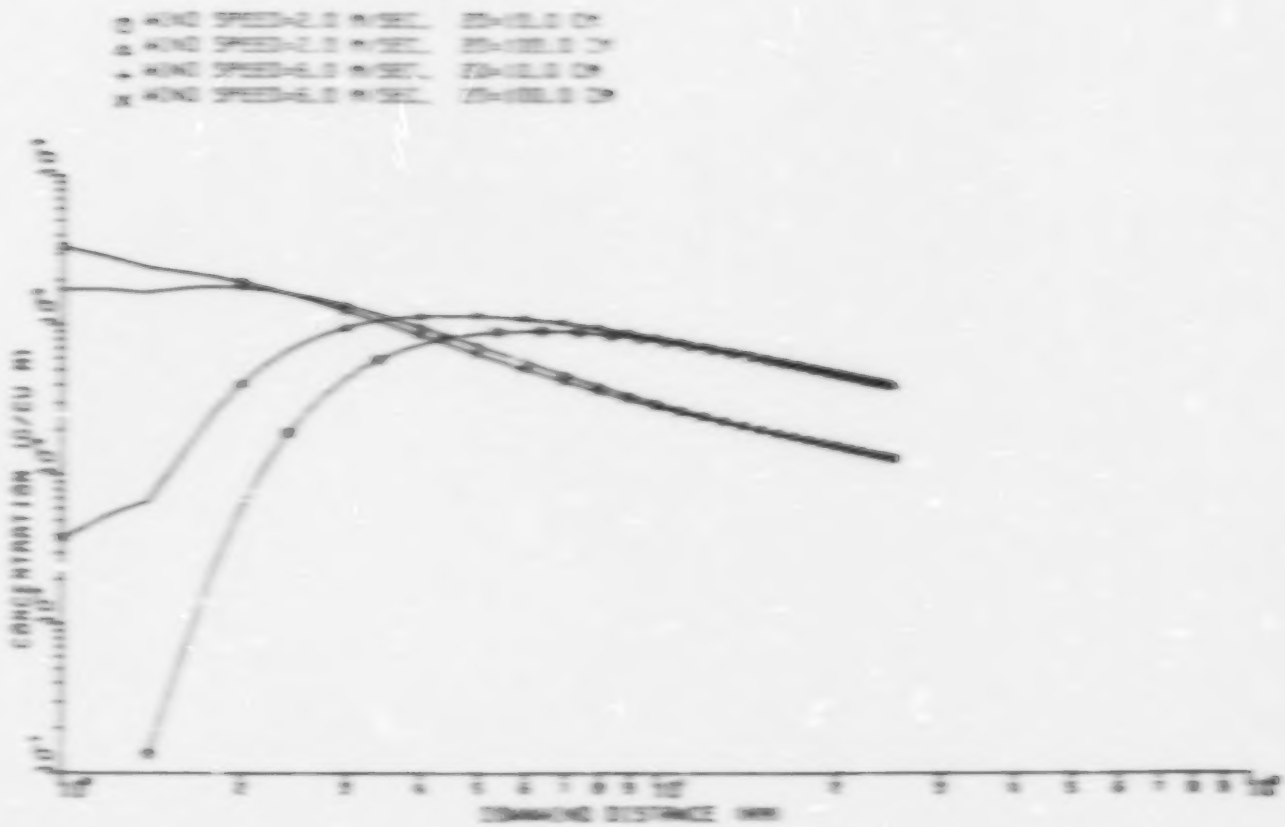

Figure C-5a. Effect of surface roughness upon ground level air concentrations for stability Class A at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

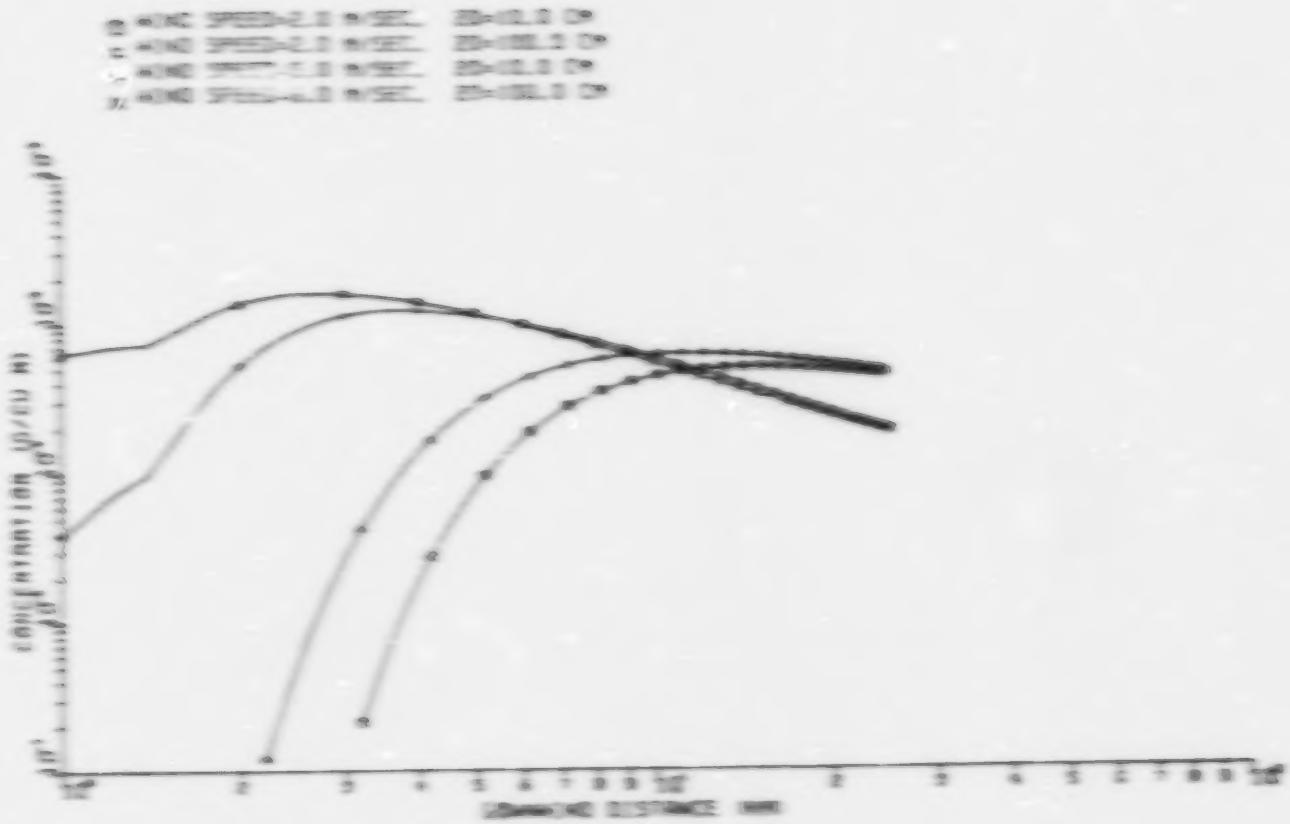

Figure C-3b. Effect of surface roughness upon ground level air concentrations for stability Class B at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

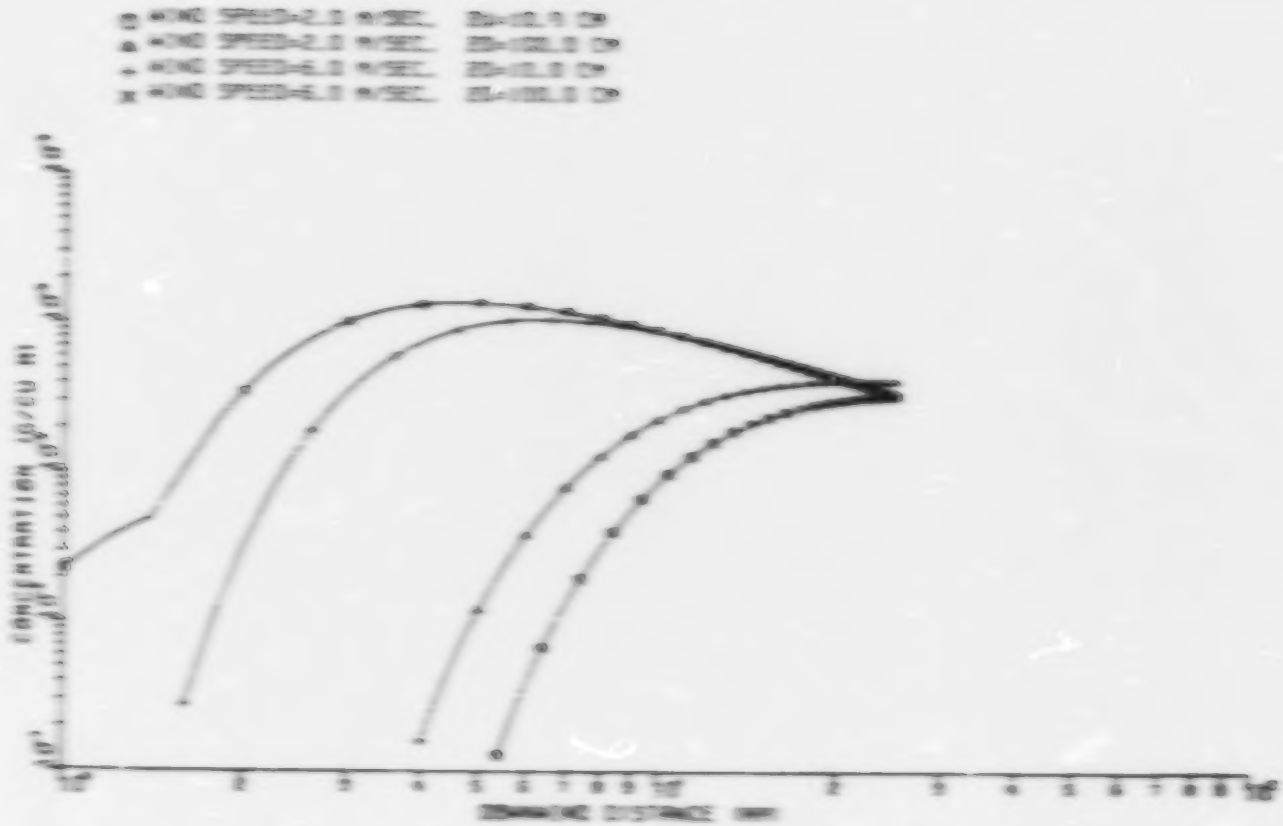

Figure C-1c. Effect of surface roughness upon ground level air concentrations for stability Class C at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

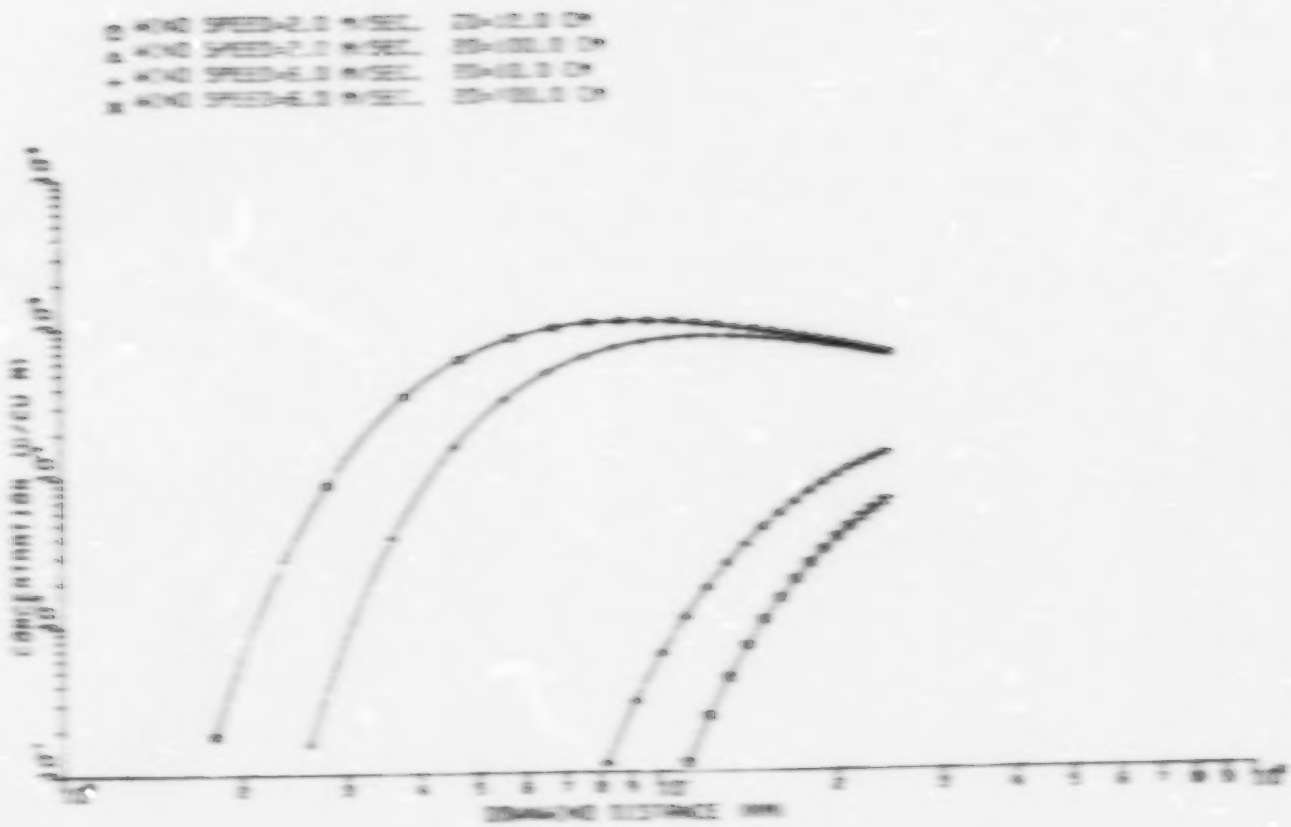

Figure C-36. Effect of surface roughness upon ground level air concentrations for stability Class D at the Canal Plant. F. B. Smith σ_z and Pasquill-Gifford σ_y curves used. Flat terrain assumed

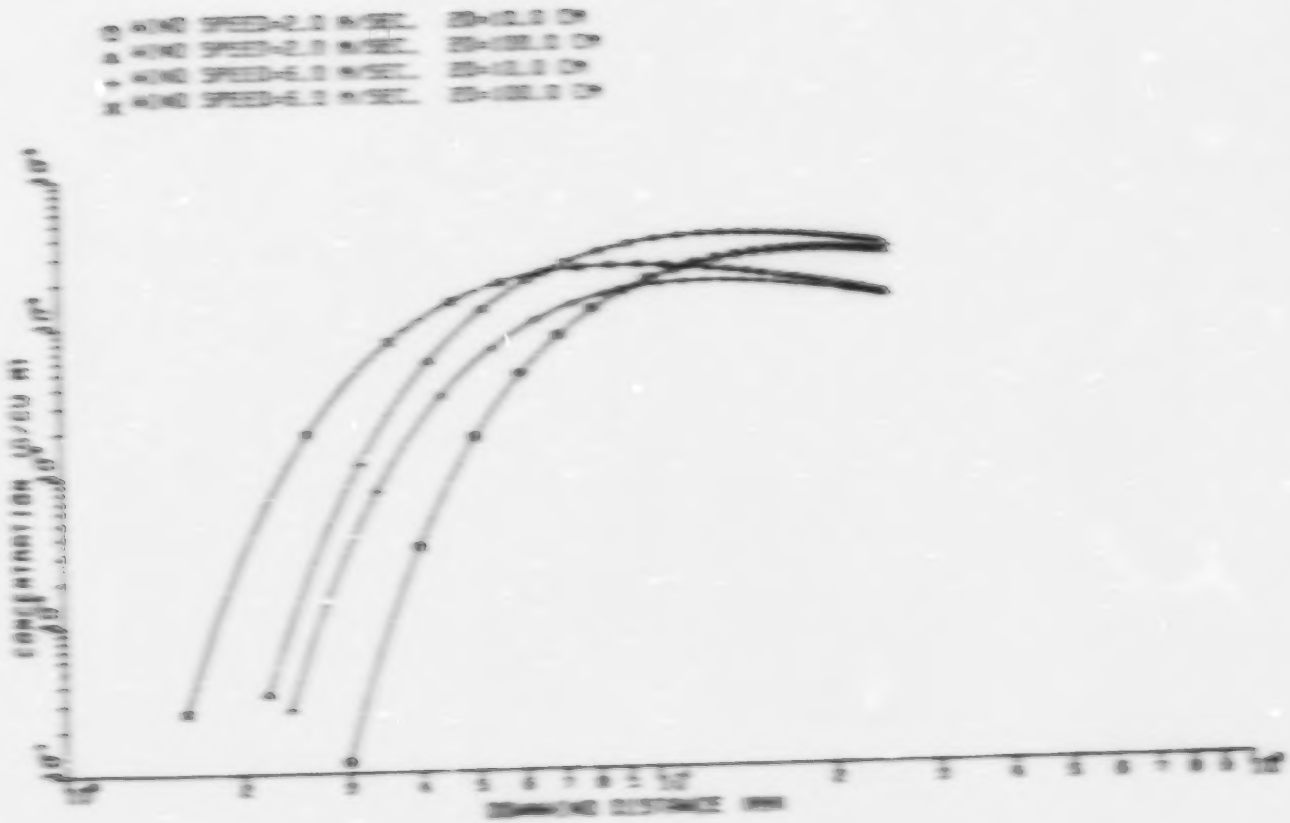

Figure C-3a. Effect of surface roughness upon ground level air concentrations for stability Class F at the Canal Plant. F. B. Smith σ_z and Pasquill-Gifford σ_y curves used. Flat terrain assumed

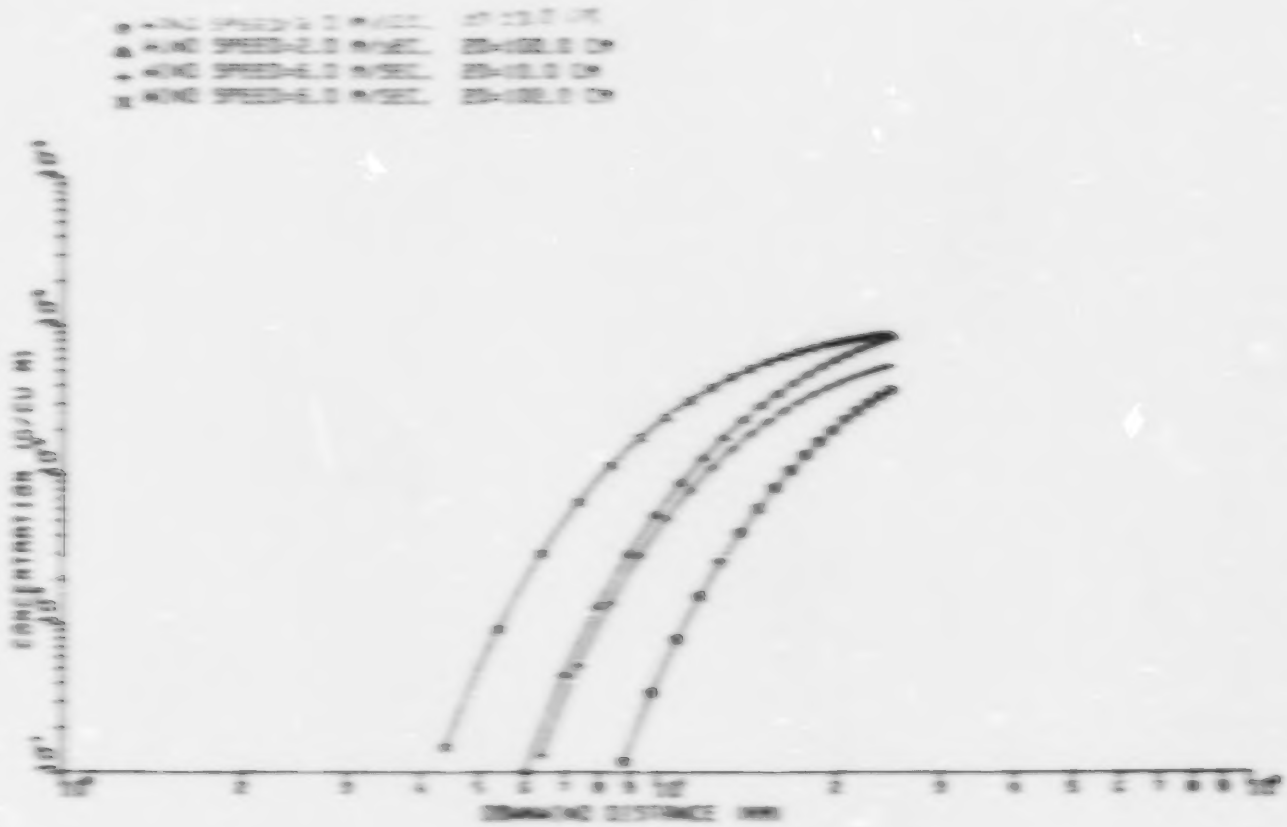

Figure C-5L. Effect of surface roughness upon ground level air concentrations for stability Class F at the Canal Plant. F. B. Smith σ_z and Pasquill-Gifford σ_z curves used. Flat terrain assumed

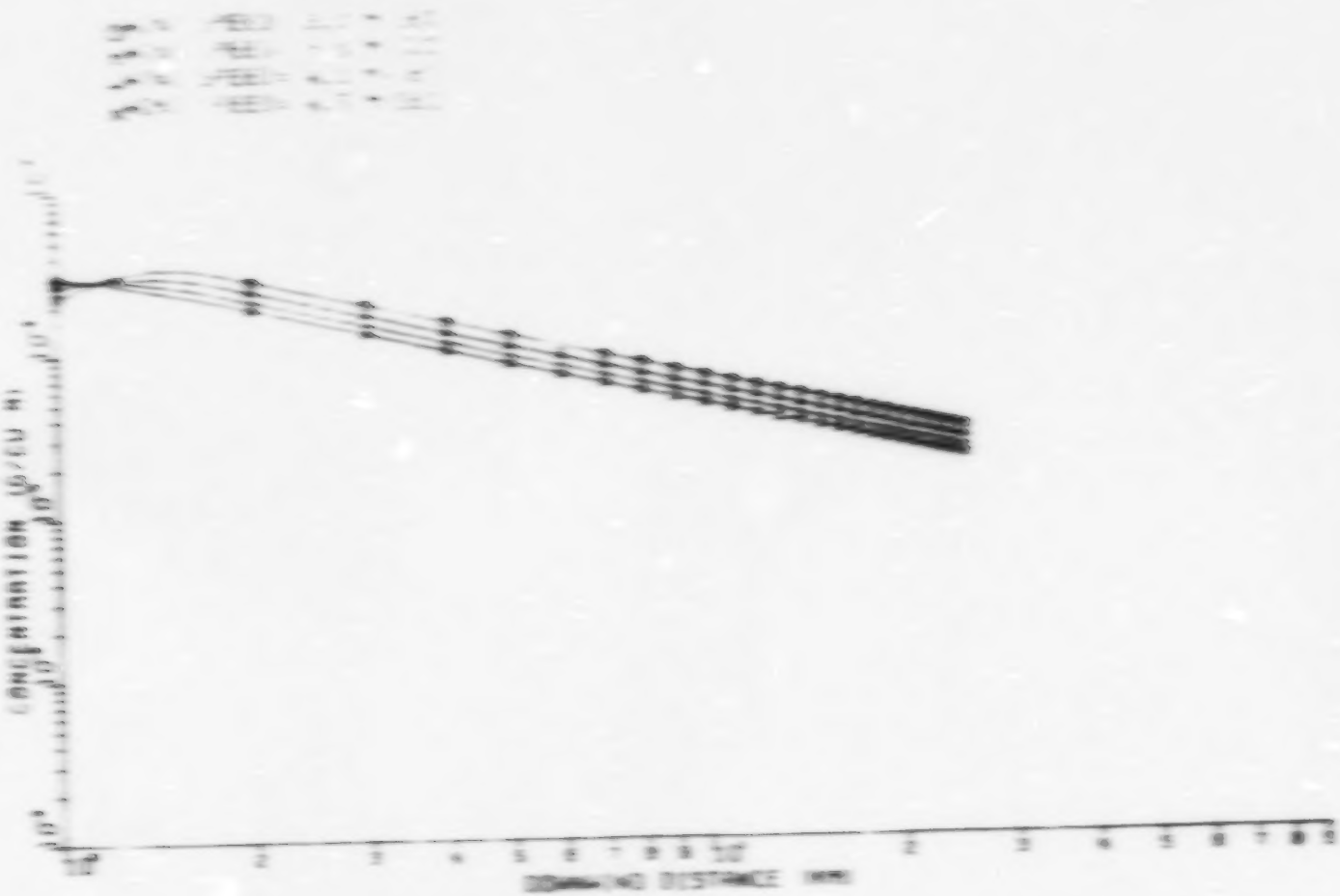

Figure C-4a. Plume centerline concentration versus downwind distance for stability Class A at the Muskingum Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

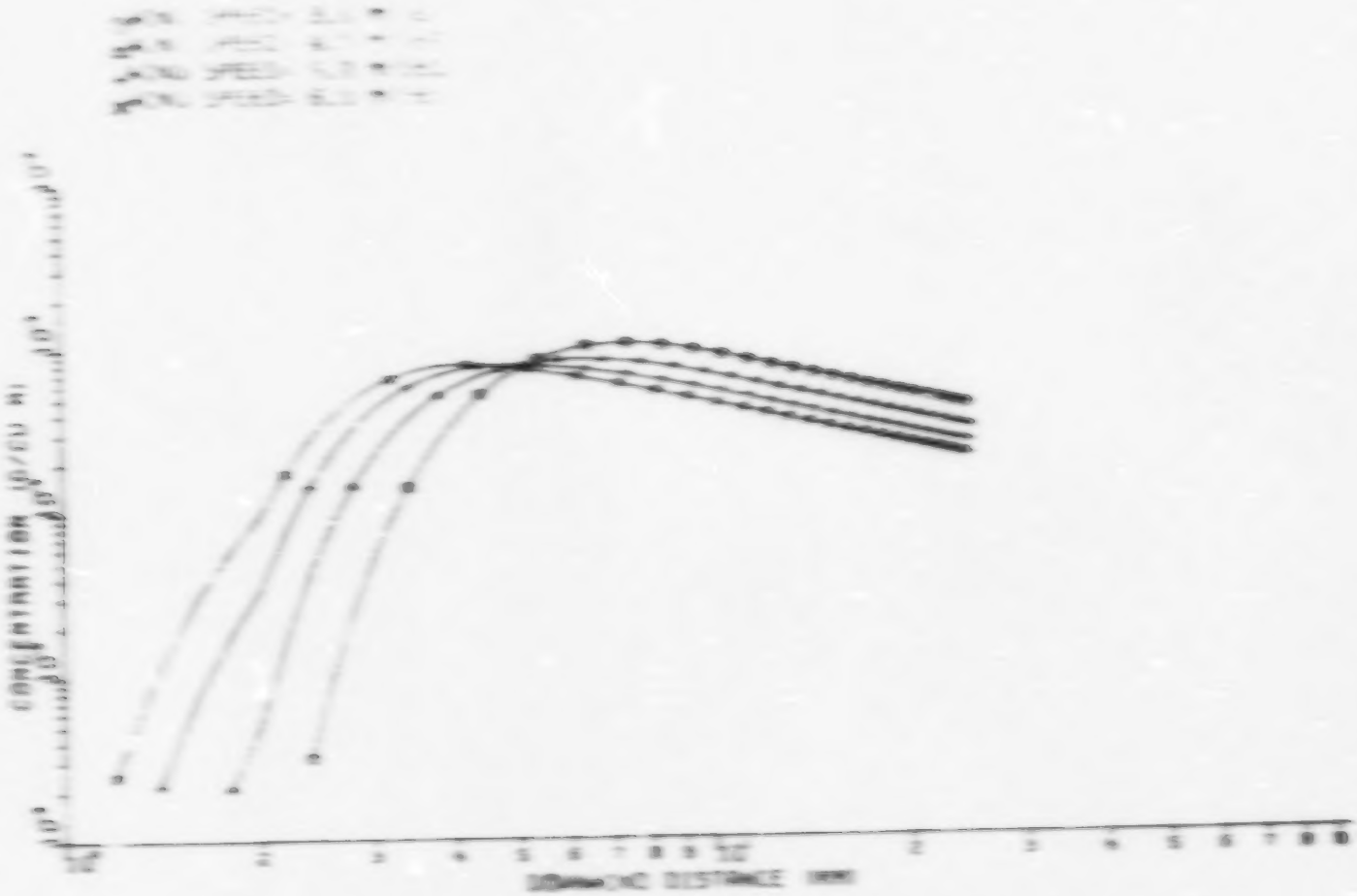

Figure C-4b. Plume centerline concentration versus downwind distance for stability Class D at the Washington Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

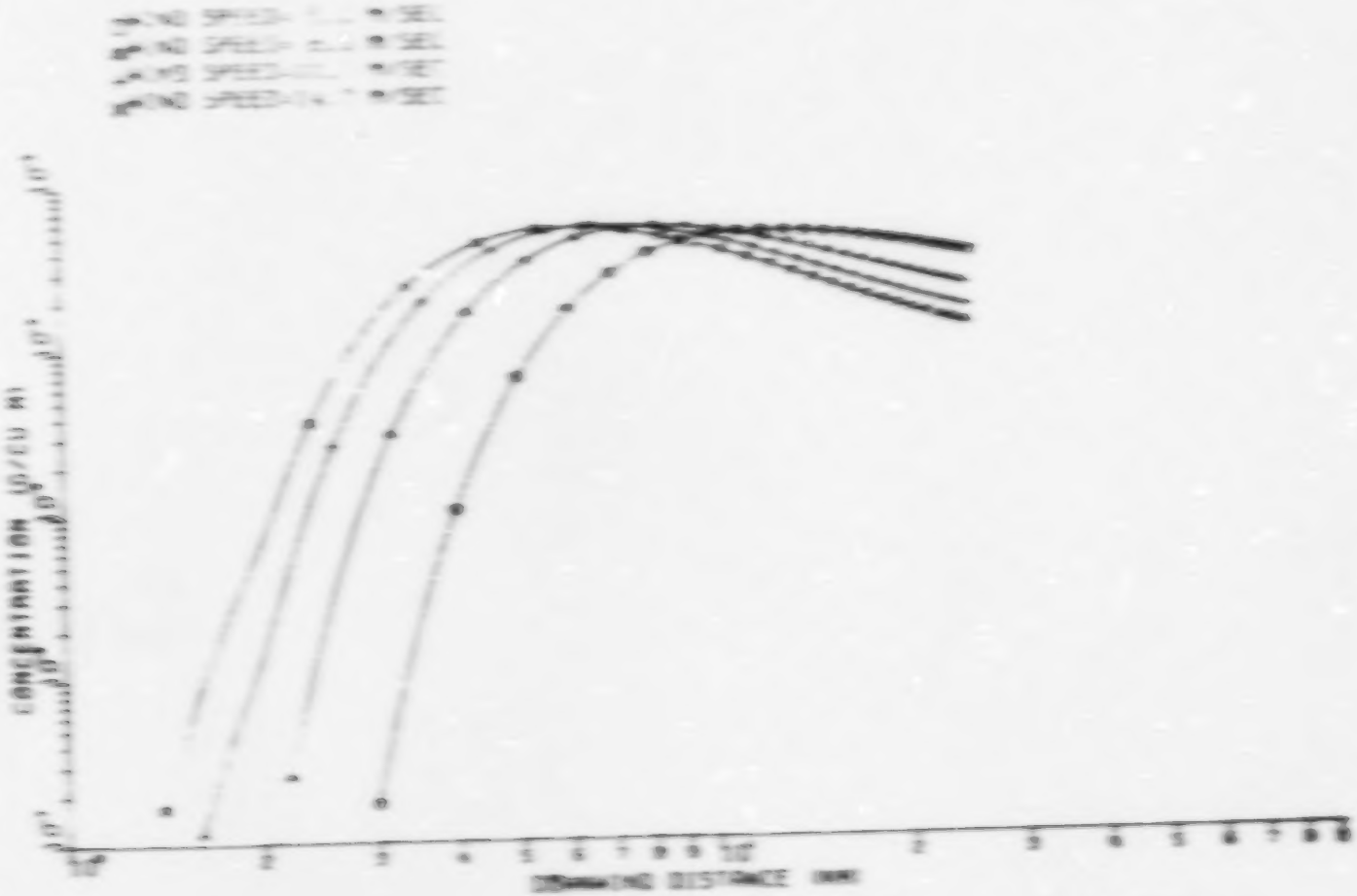

Figure C-6c. Plume centerline concentration versus downwind distance for stability Class C at the Nuklinger Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

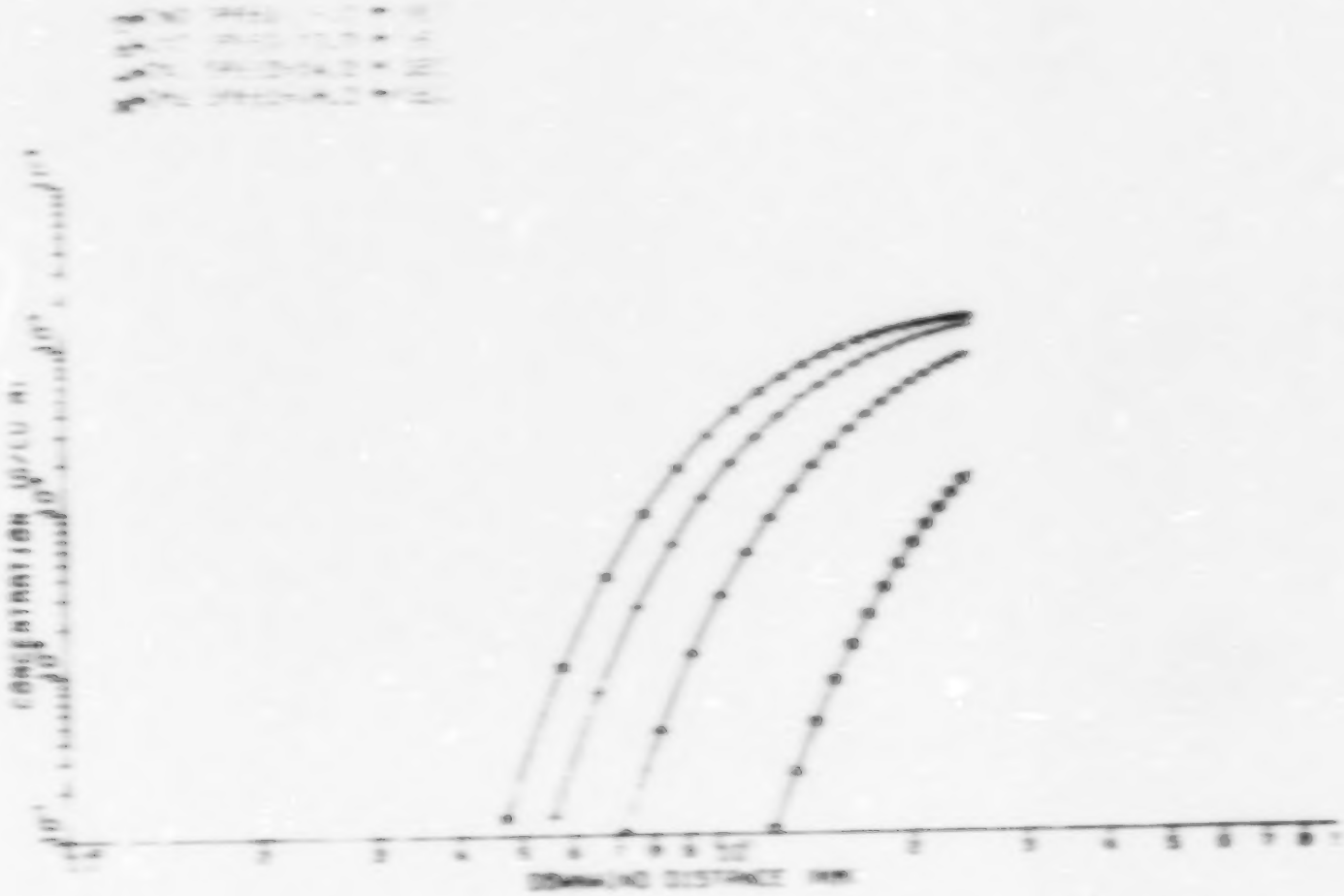

Figure C-4d. Plume centerline concentration versus downwind distance for stability Class D at the Washington Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

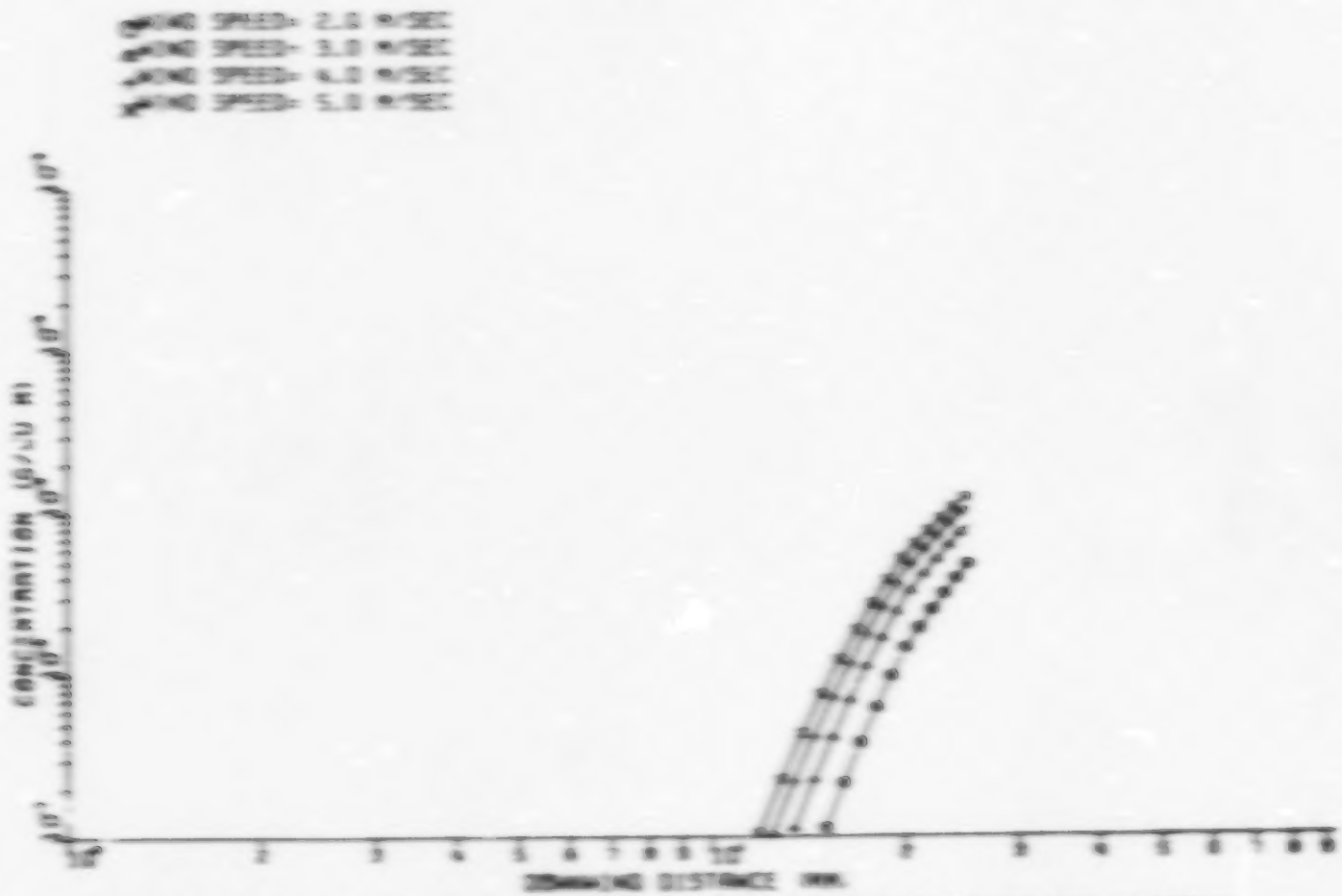

Figure C-4a. Plume centerline concentration versus downwind distance for stability Class E at the Waukegan Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

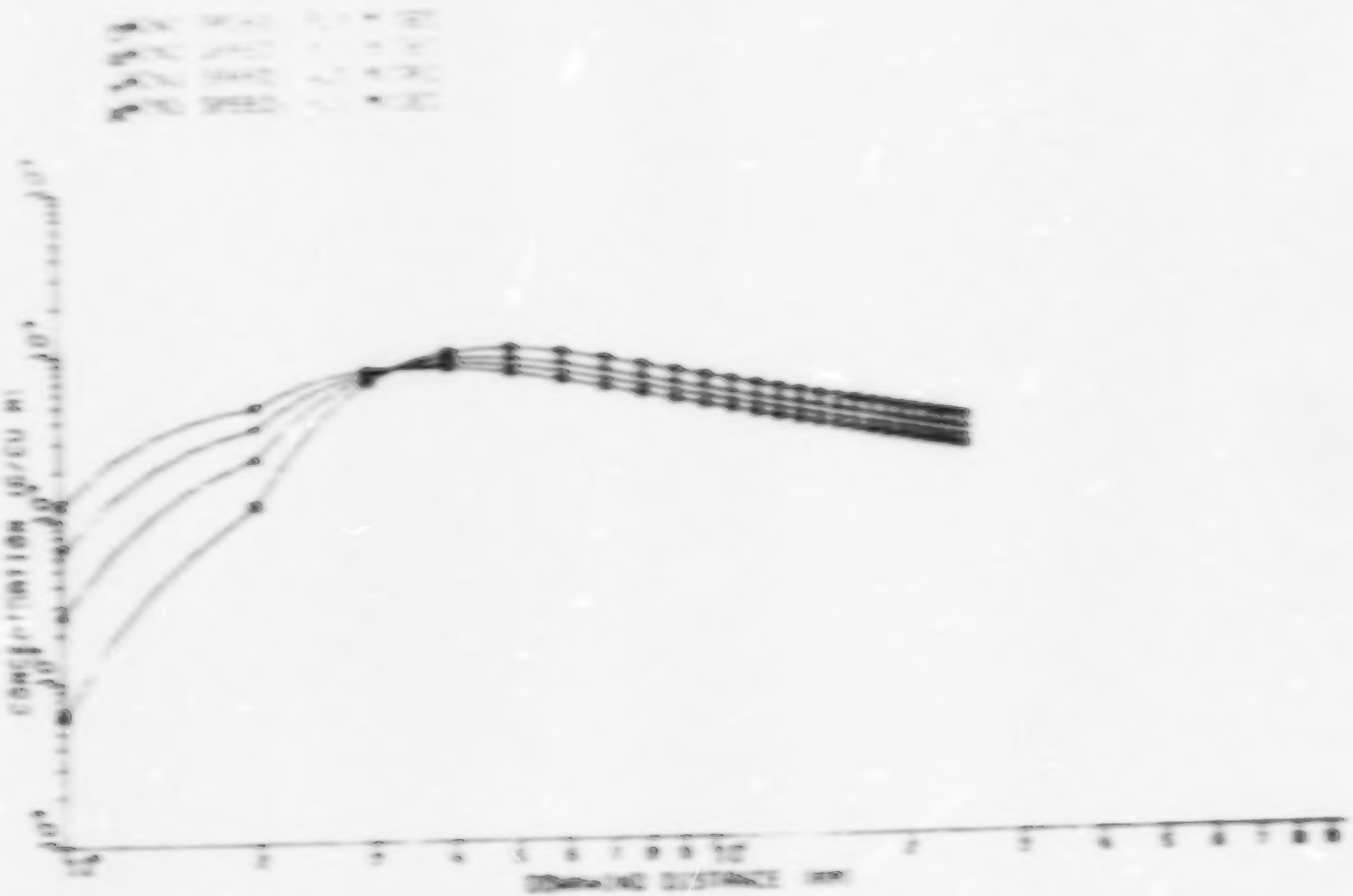

Figure C-1a. Plume centerline concentration versus downwind distance for stability Class A at the Hanford Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

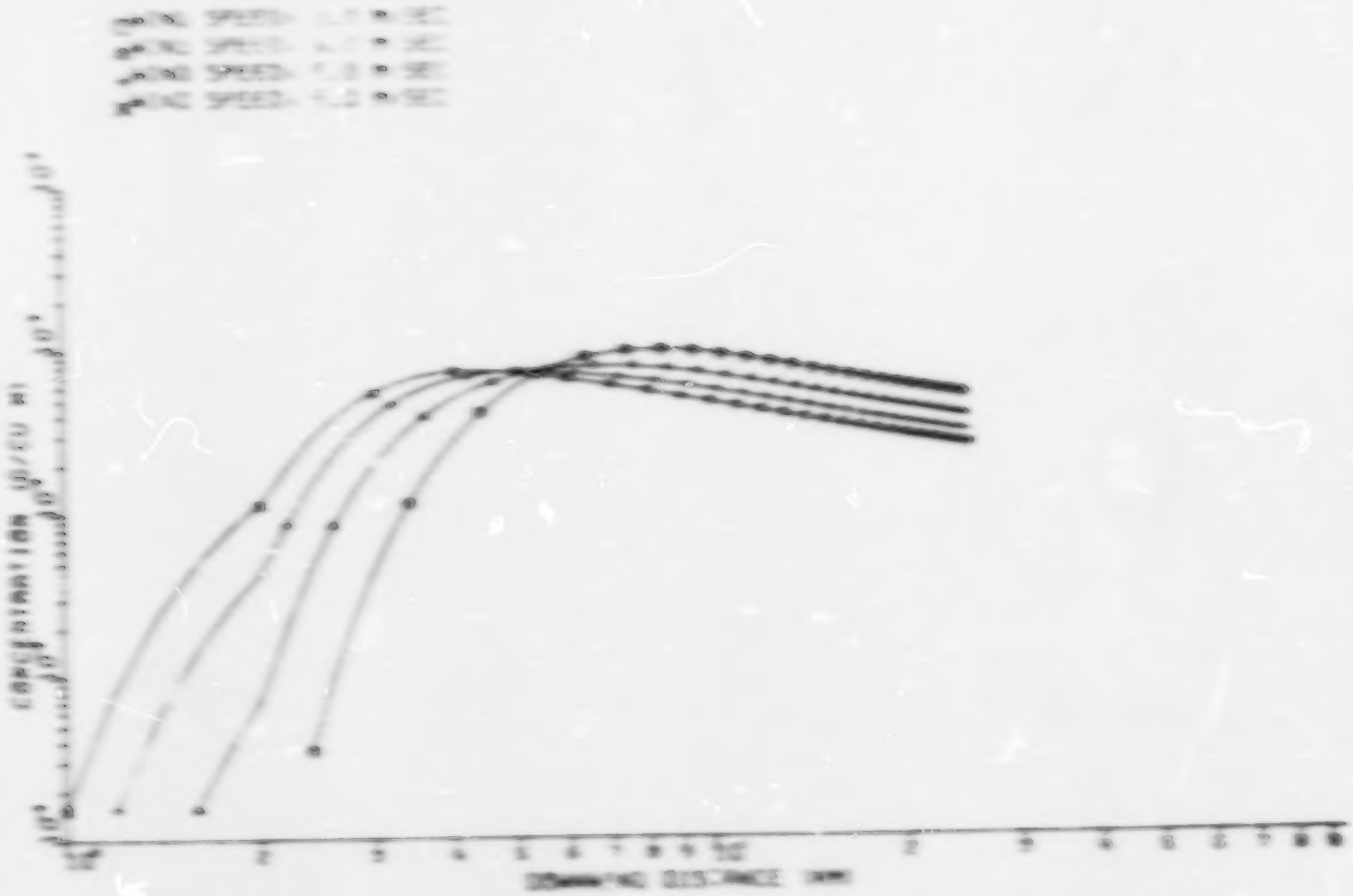

Figure C-7b. Plume centerline concentration versus downwind distance for stability Class D at the Washington Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

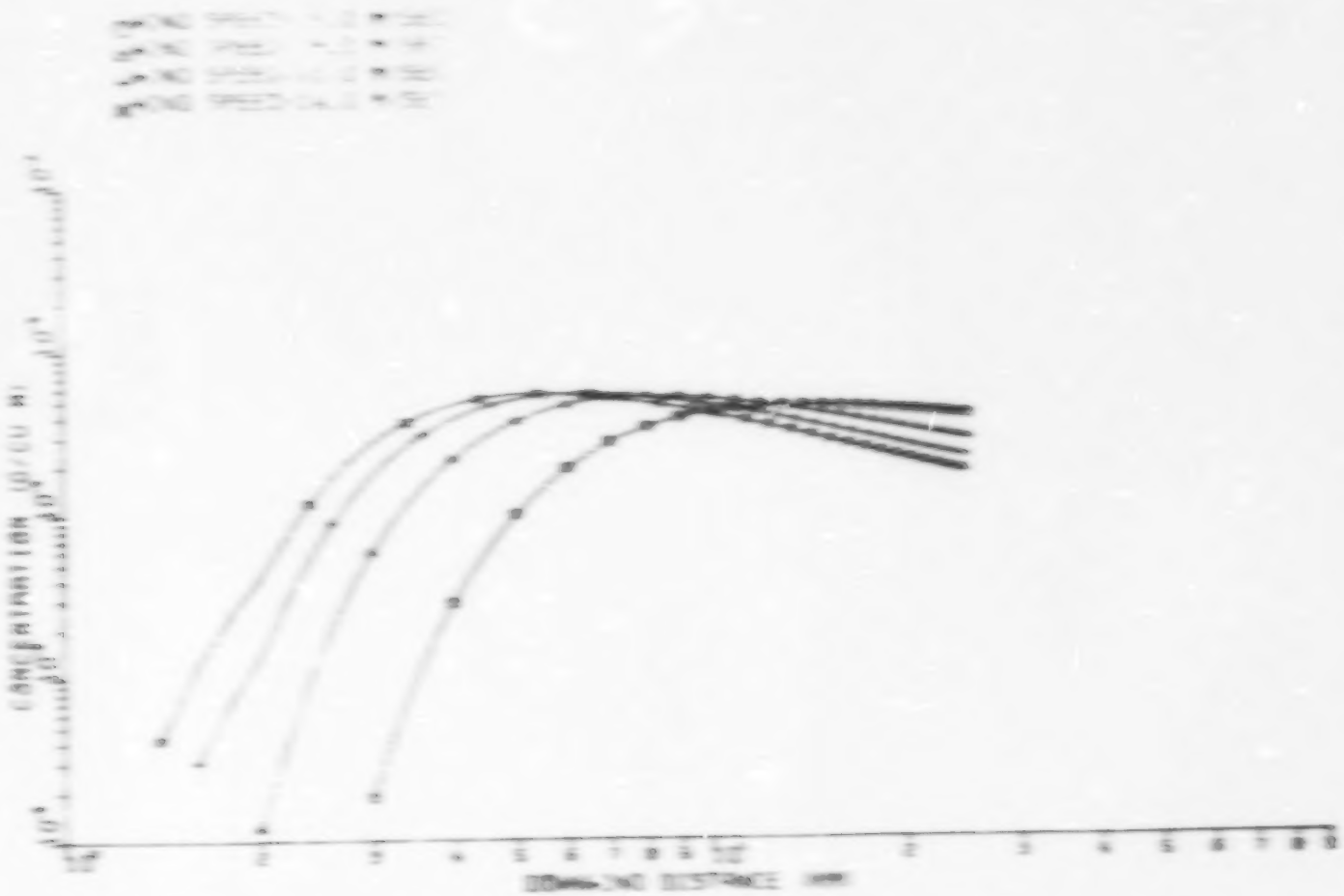

Figure C-7c. Plume centerline concentration versus downwind distance for stability Class C at the Muskingum Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

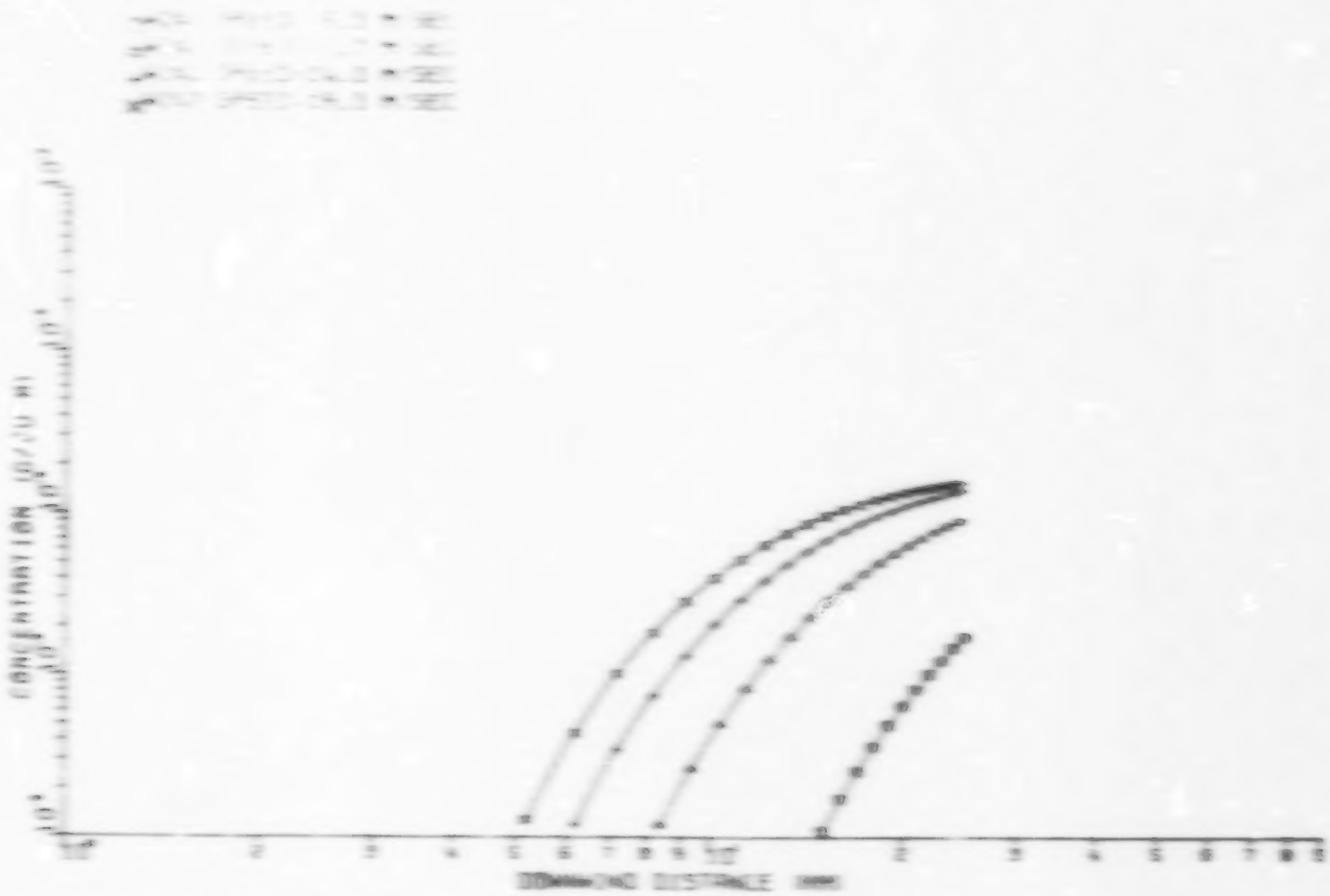

Figure C-7d. Plume centerline concentration versus downwind distance for stability Class D at the Muskingum Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

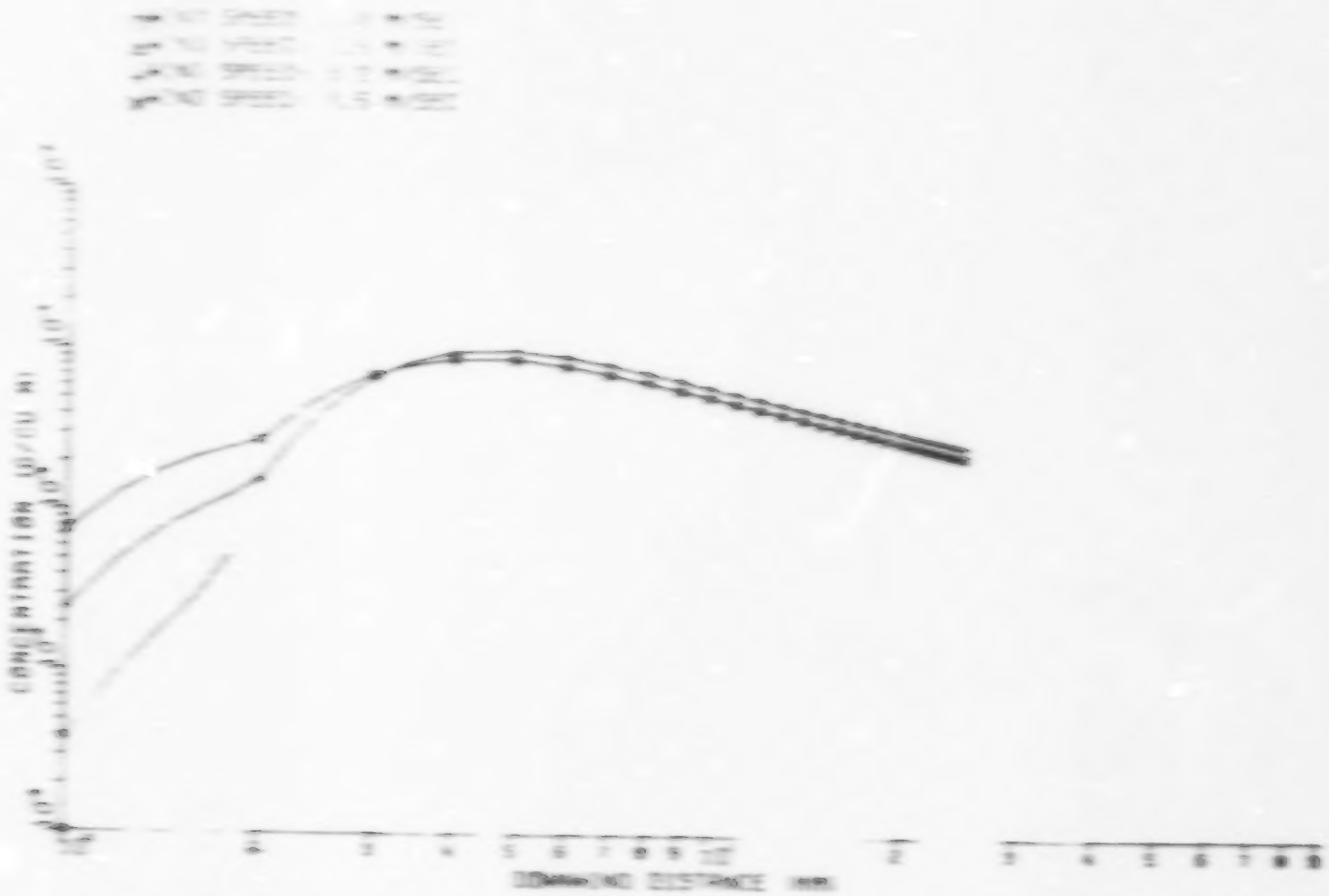

Figure C-8a. Plume centerline concentration versus downwind distance for stability Class B2 at the Muskingum Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

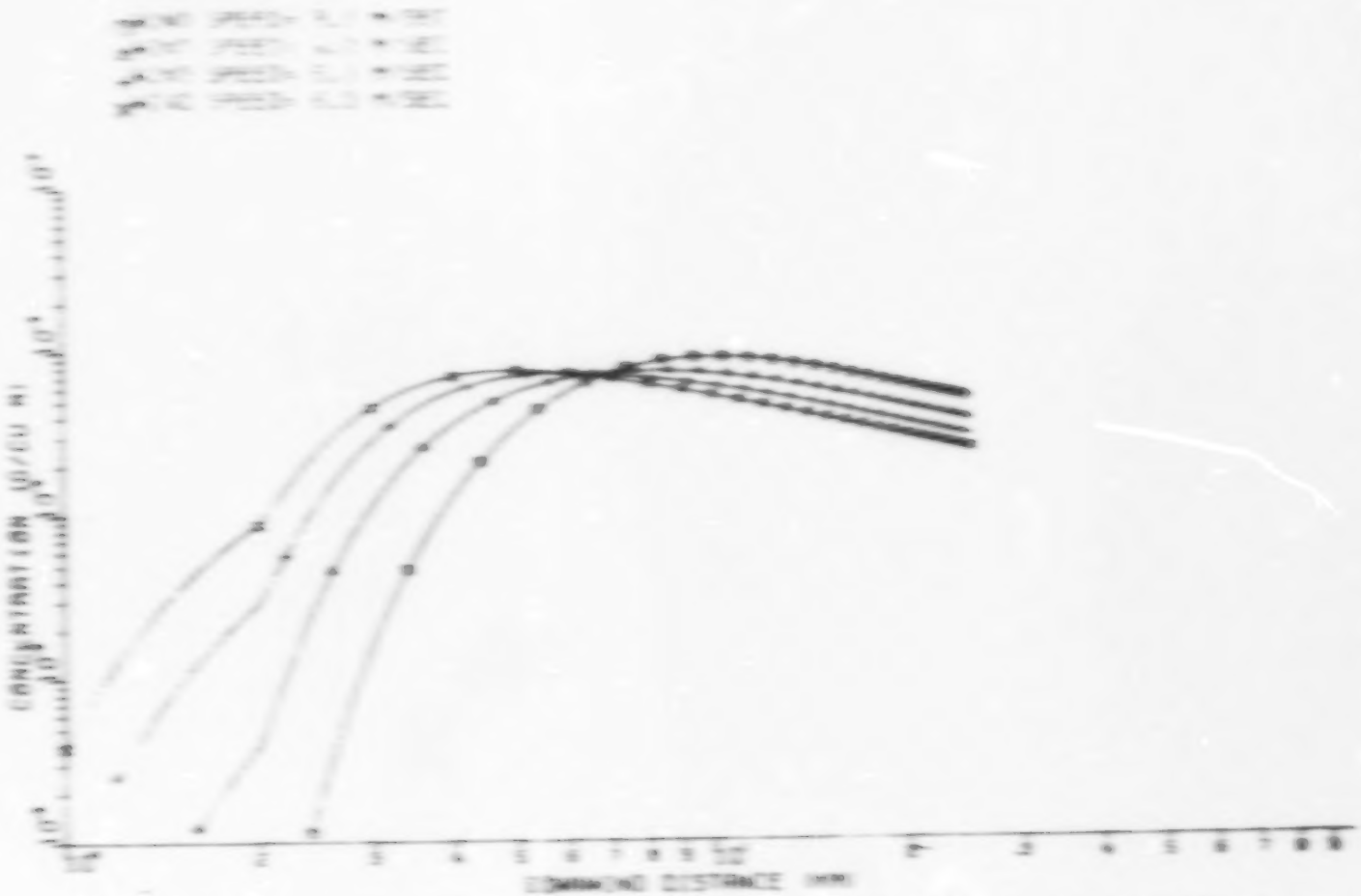

Figure C-8b. Plume centerline concentration versus downwind distance for stability Class E at the Muskingum Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

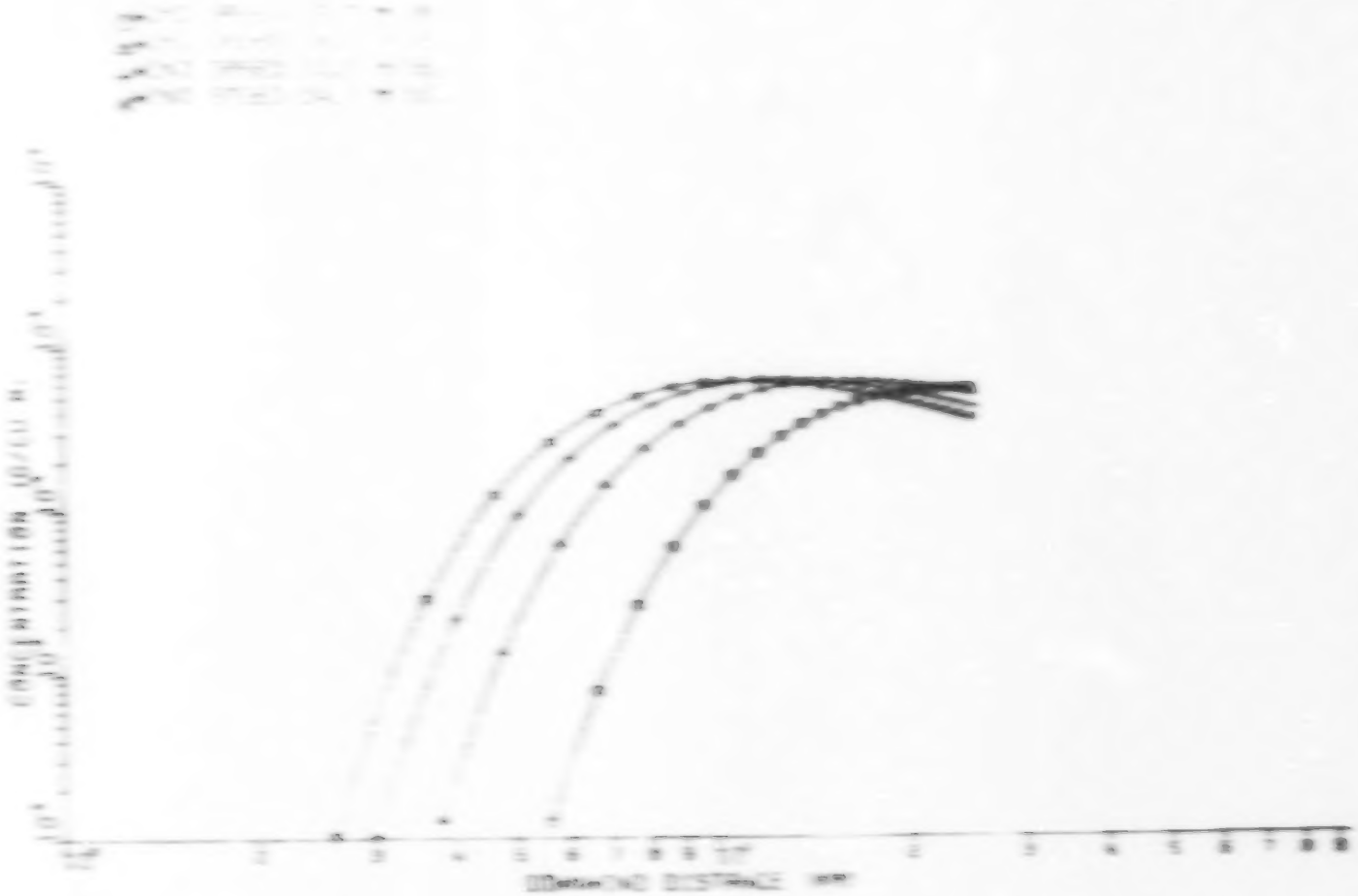

Figure C-4b. Plume centerline concentration versus downwind distance for stability Class C at the Washington Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

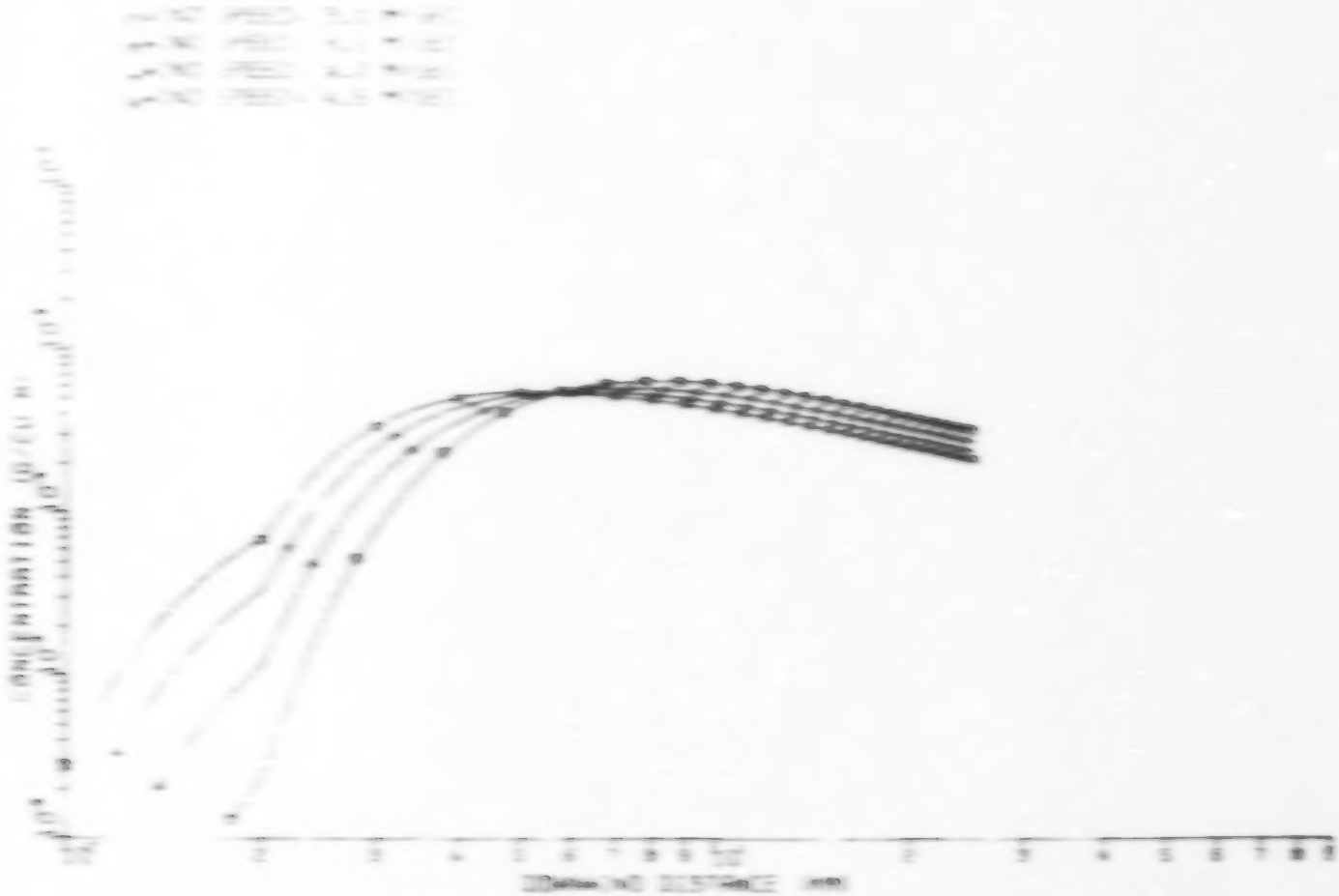

Figure C-9b. Plume centerline concentration versus downwind distance for stability Class A at the Washington Plant. F. A. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

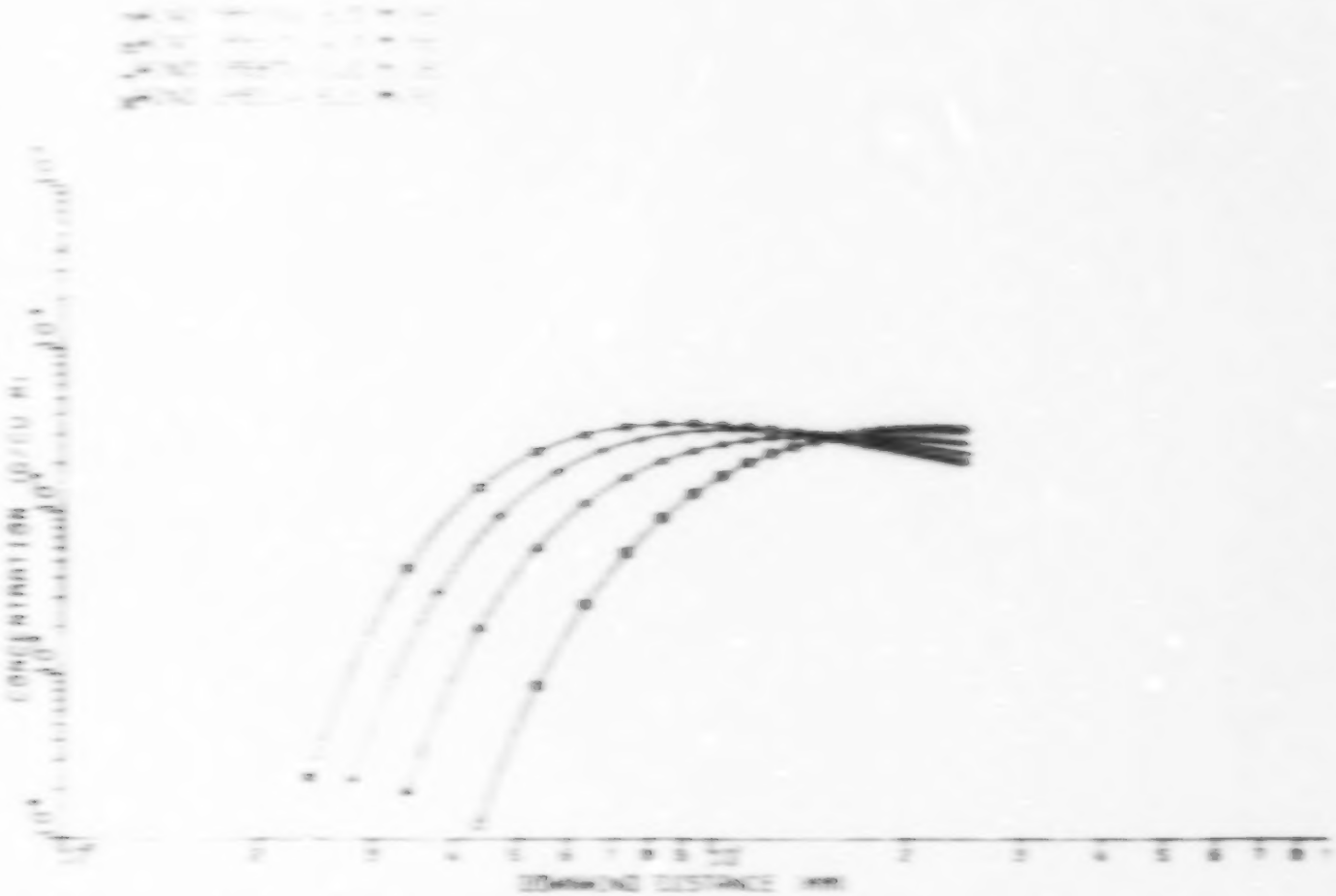

Figure C-9b. Plume centerline concentration versus downwind distance for stability Class E at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

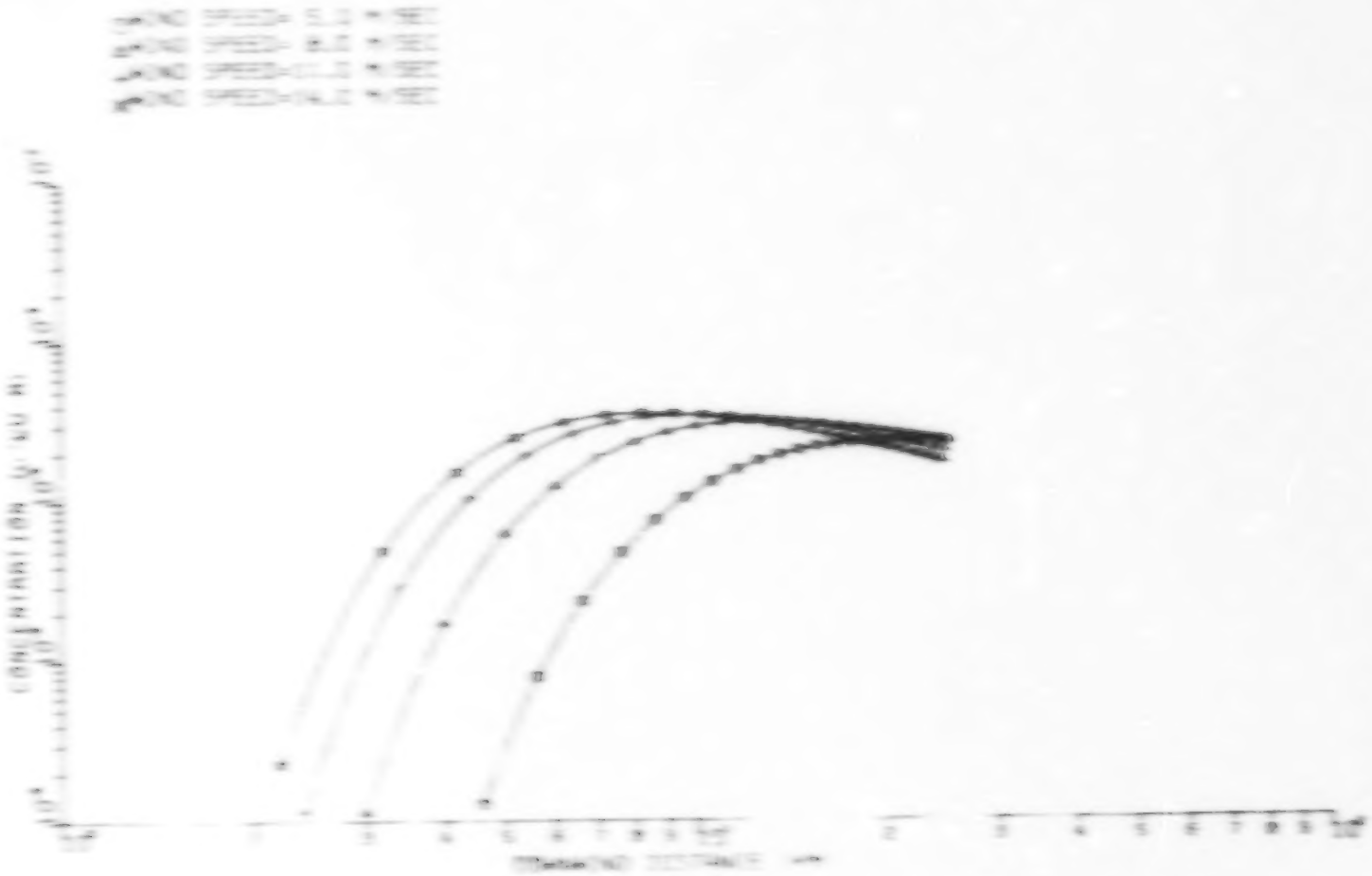

Figure C-4b. Plume centerline concentration versus downwind distance for stability Class C at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

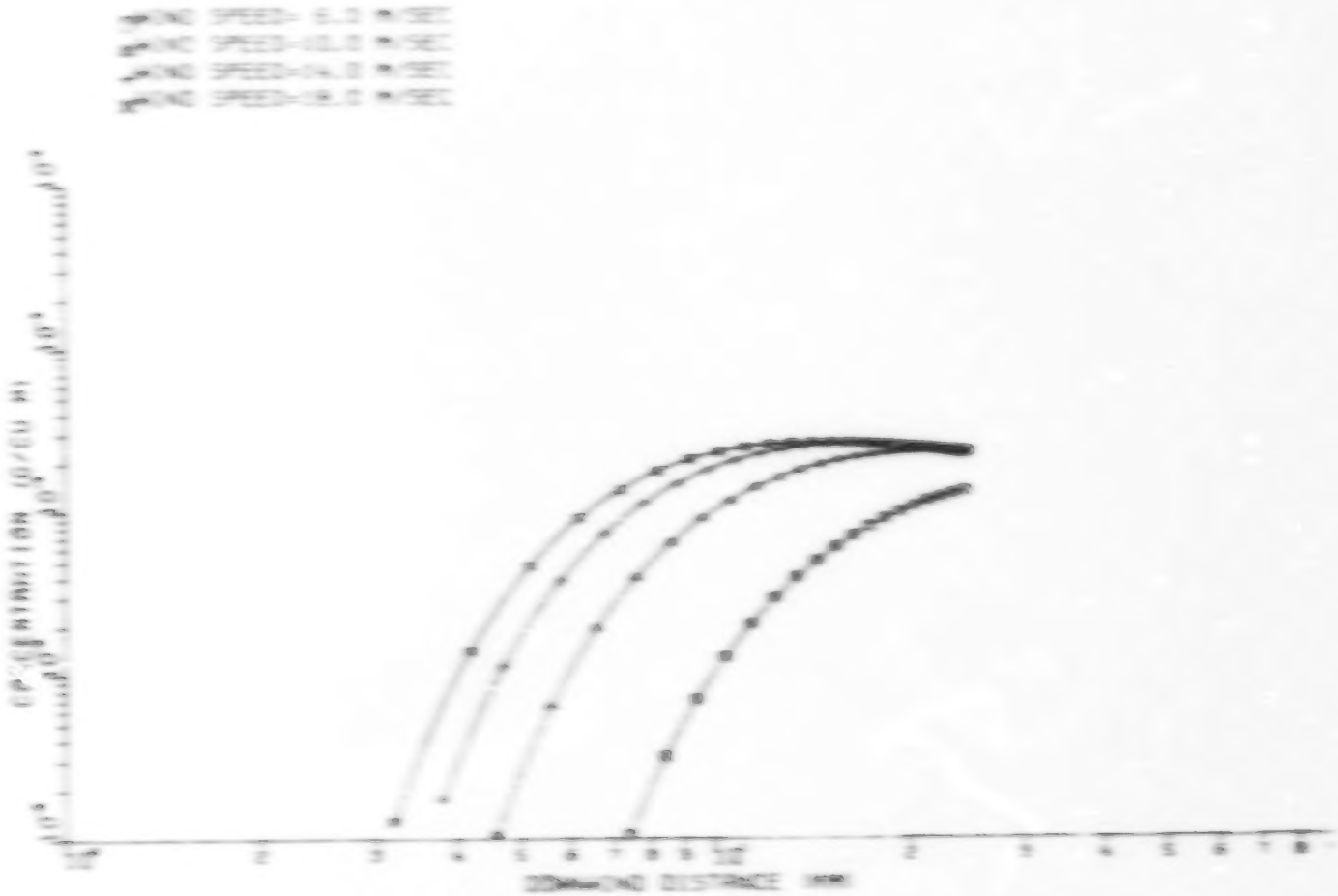

Figure C-46. Plume centerline concentration versus downwind distance for stability Class D at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

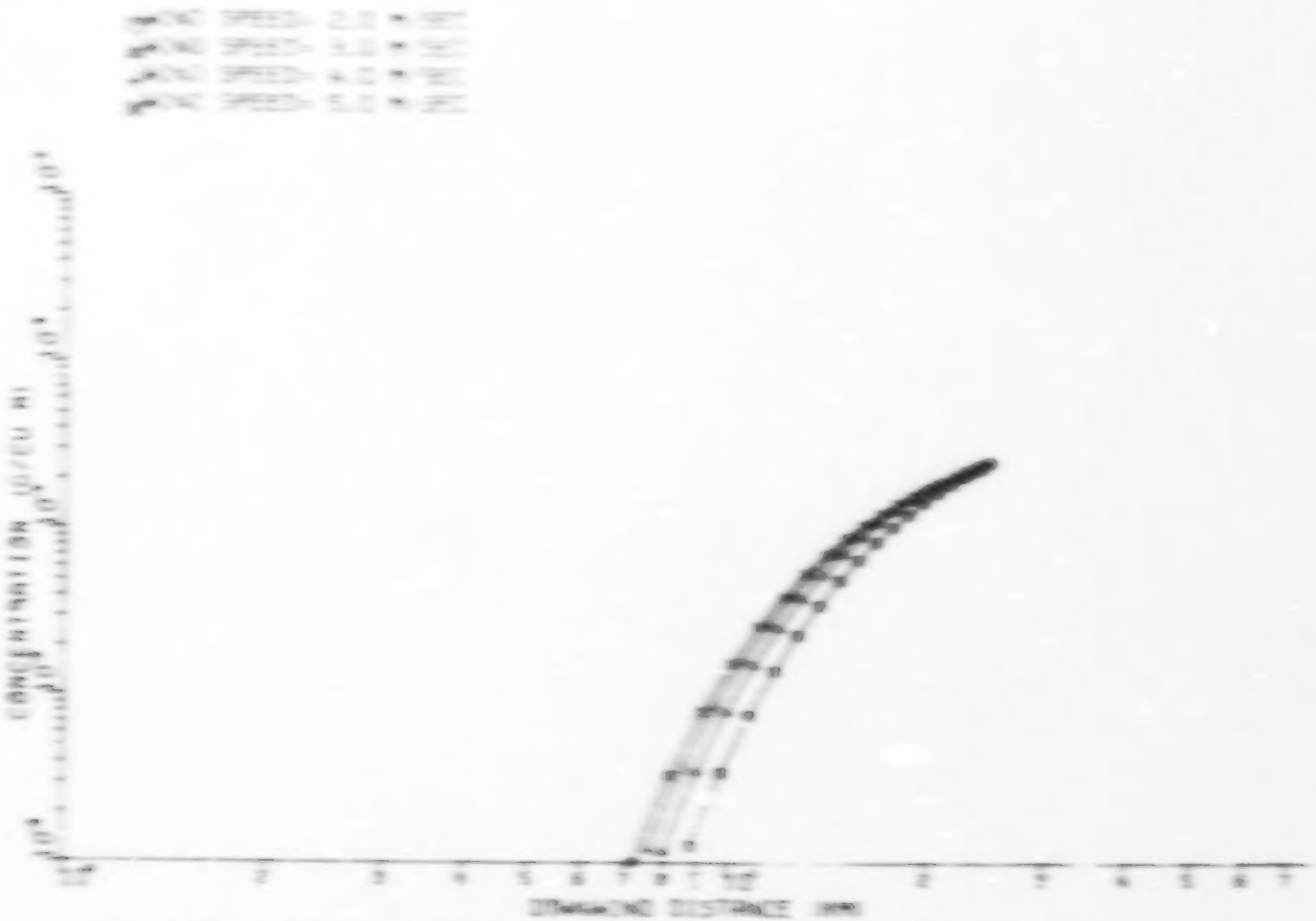

Figure C-4b. Plume centerline concentration versus downwind distance for stability Class E at the Waukegan Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top